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ALTITUDE DEVELOPMENTAL TESTING OF THE J-2S ROCKET ENGINE IN ROCKET DEVELOPMENT TEST CELL (J-4) (TESTS J-4-1001-04 AND J-4-1001-05)

C. R. Tinsley and C. E. Pillow

ARO, Inc.

July 1970

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FOREWORD

The work reported herein was sponsored by the National Aeronautics and Space Administration (NASA), Marshall Space Flight Center (MSFC) (PM-EJ), under Program Element 921E, Project 9194.

The results of the tests presented were obtained by ARO, Inc. (a subsidiary of Sverdrup & Parcel and Associates, Inc.), contract operator of the Arnold Engineering Development Center (AEDC), Air Force Systems Command (AFSC), Arnold Air Force Station, Tennessee, under Contract F40600-71-C-0002. Program direction was provided by NASA/MSFC; technical and engineering liaison was provided by North American Rockwell Corporation, Rocketdyne Division, manufacturer of the J-2S rocket engine, and McDonnell Douglas Astronautics Company, manufacturer of the S-IVB stage. The testing reported herein was conducted on July 17 and 29, 1969, in Rocket Development Test Cell (J-4) of the Engine Test Facility (ETF) under ARO Project No. RN1001. The manuscript was submitted for publication on May 14, 1970.

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This technical report has been reviewed and is approved.

Walter C. Knapp Lt Colonel, USAF AF Representative, ETF Directorate of Test	Roy R. Croy, Jr. Colonel, USAF Director of Test

ABSTRACT

Five firings of the Rocketdyne J-2S rocket engine were conducted in Rocket Development Test Cell (J-4) of the Engine Test Facility on July 17 and 29, 1969. These firings were accomplished during test periods J4-1001-04 and J4-1001-05 at pressure altitudes ranging from 85,000 to 101,000 ft at engine start. The primary objectives of these test periods were to (1) determine if main-stage conditions which existed during sea-level testing of engine S/N J-113 would result in similar abnormal oxidizer dome vibrations in the 4400- to 4700-Hz frequency range during altitude testing of engine J-112-E, (2) evaluate high thrust idle-mode operation with a simulated full-face oxidizer flow injector configuration, and (3) document effects of closing the thrust chamber bypass valve during high thrust idle-mode operation. Altitude testing did not result in abnormal (greater than 100 g rms) oxidizer dome vibration in the 4400- to 4700-Hz range during test period 04. The thrust chamber bypass valve closing resulted in a 65°F increase in fuel injection temperature; however, stabilized high thrust idle-mode operation was attained during test period 05.

CONTENTS

APPENDIXES

NOMENCLATURE

A — Area, sq in.

ASI — Augmented spark igniter

CCP — Customer connect panel

EBW — Exploding bridgewire

FM — Frequency modulation

MFV — Main fuel valve

MOV — Main oxidizer valve

O/F — Propellant mixture ratio, oxidizer-to-fuel, by weight

SPTS	Solid-propellant turbine starter
T/C	Thrust chamber
t-0	Time at which helium control and idle-mode solenoids are energized; engine start
VSC	Vibration safety counts, defined as engine vibration in excess of 150 g rms in a 960- to 6000-Hz frequency range

SUBSCRIPTS

f	Force
m	Mass
t	Throat

SECTION I
INTRODUCTION

Testing of the Rocketdyne J-2S rocket engine using an S-IVB battleship stage has been in progress at AEDC since December 1968. Reported herein are the results of five firings of engine S/N J-112-1E conducted during test periods J4-1001-04 and J4-1001-05 on July 17 and 29, 1969, respectively. The primary objectives of these test periods were to (1) determine if main-stage conditions which existed during sea-level testing of engine S/N J-113 would result in similar abnormal oxidizer dome vibrations in the 4400- to 4700-Hz frequency range during altitude testing of engine S/N J-112-1E, (2) evaluate high thrust idle-mode operation with a simulated full-face oxidizer flow injector configuration, and (3) document effects of the thrust chamber bypass valve closing during high thrust idle-mode operation.

The firings reported herein were accomplished in Rocket Development Test Cell (J-4) (Figs. 1 and 2, Appendix I) of the Engine Test Facility (ETF) at pressure altitudes ranging from 85,000 to 101,000 ft (geometric pressure altitude, Z, Ref. 1) at engine start signal. Data collected to accomplish the test objectives are presented herein. The results of the previous test period are presented in Ref. 2.

SECTION II
APPARATUS

2.1 TEST ARTICLE

The test article was a J-2S rocket engine (Fig. 3) designed and developed by Rocketdyne Division of North American Rockwell Corporation. The engine uses liquid oxygen and liquid hydrogen as propellants and is designed to operate either in idle mode at a nominal thrust of 5000 lbf and mixture ratio of 2.5, or at main stage at any precalibrated thrust level between 230,000 and 265,000 lbf at a mixture ratio of 5.5. The engine design is capable of transition from idle-mode to main-stage operation after a minimum of 1-sec idle mode utilizing a solid-propellant turbine starter; from main stage the engine can either be shut down or make a transition back to idle-mode operation before shutdown. An S-IVB battleship stage was used to supply propellants to the engine. A schematic of the battleship stage is presented in Fig. 4.

Listings of major engine components and engine orifices for these test periods are presented in Tables I and II, respectively (Appendix II). All engine modifications and component replacements performed during this report period are presented in Tables III and IV, respectively.

2.1.1 J-2S Rocket Engine

The J-2S rocket engine (Figs. 3 and 5, Refs. 3 and 4) features the following major components:

1. Thrust Chamber—The tubular-walled, bell-shaped thrust chamber consists of an 18.6-in.-diam combustion chamber with a throat

diameter of 12.192 in., a characteristic length (L*) of 35.4, and a divergent nozzle with an expansion ratio of 39.62. Thrust chamber length (from the injector flange to the nozzle exit) is 108.6 in. Cooling is accomplished by the circulation of engine fuel flow downward from the fuel manifold through 180 tubes and then upward through 360 tubes to the injector and by film cooling inside the combustion chamber.

2. Thrust Chamber Injector–The injector is a concentric-orificed (concentric fuel orifices around the oxidizer post orifices), porous-faced injector. Fuel and oxidizer injector orifice areas are 19.2 and 5.9 sq in., respectively. The oxidizer portion is compartmented, the outer compartment supplying oxidizer during main stage only. The porous material forming the injector face allows approximately 3.5 percent of main-stage fuel flow to transpiration cool the face of the injector.

3. Augmented Spark Igniter–The augmented spark igniter unit is mounted on the thrust chamber injector and supplies the initial energy source to ignite propellants in the main combustion chamber. The augmented spark igniter chamber is an integral part of the thrust chamber injector. Fuel and oxidizer are ignited in the combustion area by two spark plugs.

4. Fuel Turbopump–The fuel turbopump is a one and one-half stage, centrifugal-flow unit, powered by a direct-drive, two-stage turbine. The pump is self-lubricated and nominally produces, at the 265,000-lbf thrust-rated condition, a head rise of 60,300 ft of liquid hydrogen at a flow rate of 9750 gpm for a rotor speed of 29,800 rpm.

5. Oxidizer Turbopump–The oxidizer turbopump is a single-stage, centrifugal-flow unit, powered by a direct-drive, two-stage turbine. The pump is self-lubricated and nominally produces, at the 265,000-lbf thrust rated condition, a head rise of 3250 ft of liquid oxygen at a flow rate of 3310 gpm for a rotor speed of 10,500 rpm.

6. Propellant Utilization Valve–The motor-driven propellant utilization valve is a sleeve-type valve which is mounted on the oxidizer turbopump and bypasses liquid oxygen from the discharge to the inlet side of the pump to vary engine mixture ratio.

7. Main-Oxidizer Valve–The main oxidizer valve is a pneumatically actuated, two-stage, butterfly-type valve located in the oxidizer high-pressure duct between the turbopump and the injector. The first-stage actuator positions the main oxidizer valve at a nominal 12-deg position to obtain initial main-stage-phase operation; the second-stage actuator ramps the main oxidizer valve fully open to accelerate the engine to the main-stage operating level.

8. Main-Fuel Valve—The main fuel valve is a pneumatically actuated, butterfly-type valve located in the fuel high-pressure duct between the turbopump and the fuel manifold.

9. Pneumatic Control Package—The pneumatic control package controls all pneumatically operated engine valves and purges.

10. Electrical Control Assembly—The electrical control assembly provides the electrical logic required for proper sequencing of engine components during operation. The logic requires a minimum of 1-sec idle-mode operation before transition to main stage.

11. Flight Instrumentation Package—The instrumentation package contains sensors required to monitor critical engine parameters. The package provides environmental control for the sensors.

12. Helium Tank—The helium tank has a volume of 4000 cu in. and provides a helium pressure supply to the engine pneumatic control system for three complete engine operational cycles.

13. Thrust Chamber Bypass Valve—The thrust chamber bypass valve is a pneumatically operated, normally open, butterfly-type valve which allows fuel to bypass the thrust chamber body during idle-mode operation.

14. Idle-Mode Valve—The idle-mode valve is a pneumatically operated, ball-type valve which supplies liquid oxygen to the idle-mode compartment of the thrust chamber injector during both idle-mode and main-stage operation.

15. Hot Gas Tapoff Valve—The hot gas tapoff valve is a pneumatically operated, butterfly-type valve which provides on-off control of combustion chamber gases to drive the propellant turbopumps.

16. Solid-Propellant Turbine Starter—The solid-propellant turbine starter provides the initial driving energy (transition to main stage) for the propellant turbopumps to prime the propellant feed systems and accelerate the turbopumps to 75 percent of the main-stage operating level. A three-start capability is provided.

2.1.2 S-IVB Battleship Stage

The S-IVB battleship stage, which is mechanically configured to simulate the S-IVB flightweight vehicle, is approximately 22 ft in diameter and 49 ft long and has a maximum propellant capacity of 43,000 lbm of liquid hydrogen and 194,000 lbm of liquid oxygen. The propellant tanks, fuel above oxidizer, are separated by a common bulkhead. Propellant prevalves, in the low-pressure ducts (external to the tanks)

interfacing the stage and engine, retain propellants in the stage until being admitted into the engine to the main propellant valves and serve as emergency engine shutoff valves. Vent and relief valve systems are provided for both propellant tanks.

Pressurization of the fuel and oxidizer tanks was accomplished by facility systems using hydrogen and helium, respectively, as the pressurizing gases. The engine-supplied gaseous hydrogen and gaseous oxygen for fuel and oxidizer tank pressurization during flight were routed to the respective facility venting system.

2.2 TEST CELL

Rocket Development Test Cell (J-4) Fig. 2, is a vertically oriented test unit designed for static testing of liquid-propellant rocket engines and propulsion systems at pressure altitudes of 100,000 ft. The basic cell construction provides a 1.5-million-lbf thrust capacity. The cell consists of four major components: (1) test capsule, 48 ft in diameter and 82 ft in height, situated at grade level and containing the test article; (2) spray chamber, 100 ft in diameter and 250 ft in depth, located directly beneath the test capsule to provide exhaust gas cooling and dehumidification; (3) coolant water, steam, nitrogen (gaseous and liquid), hydrogen (gaseous and liquid), liquid-oxygen, and gaseous-helium storage and delivery systems for operation of the cell and test article; and (4) control building, containing test article controls, test cell controls, and data acquisition equipment. Exhaust machinery is connected with the spray chamber and maintains a minimum test cell pressure before and after the engine firing and exhausts the products of combustion from the engine firing. Before a firing, the facility steam ejector, in series with the exhaust machinery, provides a pressure altitude of 100,000 ft in the test capsule. A detailed description of the test cell is presented in Ref. 5.

The battleship stage and the J-2S engine were oriented vertically downward on the centerline of the diffuser-steam ejector assembly. This assembly consisted of a diffuser duct (20 ft in diameter by 150 ft in length), a centerbody steam ejector within the diffuser duct, a diffuser insert (13.5 ft in diameter by 30 ft in length) at the inlet to the diffuser duct, and a gaseous-nitrogen annular ejector above the diffuser insert. The diffuser insert was provided for dynamic pressure recovery of the engine exhaust gases and to maintain engine ambient pressure altitude (attained by the steam ejector) during the engine firing. The annular ejector was provided to suppress steam recirculation into the test capsule during steam ejector shutdown. The test cell was also equipped with (1) a gaseous-nitrogen purge system for continuously inerting the air in-leakage of the cell; (2) a gaseous-nitrogen repressurization system for raising test cell pressure, after engine cutoff, to a level equal to spray chamber pressure and for rapid emergency inerting of the capsule; and (3) a spray chamber liquid-nitrogen supply and distribution manifold for initially inerting the spray chamber and exhaust ducting and for increasing the molecular weight of the hydrogen-rich exhaust products.

2.3 INSTRUMENTATION

Instrumentation systems were provided to measure engine, stage, and facility parameters. The engine instrumentation was comprised of (1) flight instrumentation for the measurement of critical engine parameters, and (2) facility instrumentation which was

provided to verify the flight instrumentation and to measure additional engine parameters. The flight instrumentation was provided and calibrated by the engine manufacturer; facility instrumentation was initially calibrated and periodically recalibrated at AEDC. Appendix III contains a list of all measured engine test parameters and the locations of selected sensing points.

Pressure measurements were made using strain-gage and capacitance-type pressure transducers. Temperature measurements were made using resistance temperature transducers and thermocouples. Oxidizer and fuel turbopump shaft speeds were sensed by magnetic pickup. Fuel and oxidizer flow rates to the engine were measured by turbine-type flowmeters which are an integral part of the engine. Vibrations were measured by piezoelectric accelerometers. Primary engine and stage valves were instrumented with linear potentiometers and limit switches.

The data acquisition systems were calibrated by (1) precision electrical shunt resistance substitution for the pressure transducers and resistance temperature transducer units; (2) voltage substitution for the thermocouples; (3) frequency substitution for shaft speeds and flowmeters; and (4) frequency-voltage substitution for accelerometers and capacitance-type pressure transducers.

The types of data acquisition and recording systems used during this test period were (1) a multiple-input digital data acquisition system scanning each parameter at 50 samples per second and recording on magnetic tape; (2) single-input, continuous-recording FM systems recording on magnetic tape; (3) photographically recording galvanometer oscillographs; (4) direct-inking, null-balance, potentiometer-type X-Y plotters and strip charts; and (5) optical data recorders. Applicable systems were calibrated before each test (atmospheric and altitude calibrations). Television cameras, in conjunction with video tape recorders, were used to provide visual coverage during an engine firing, as well as for replay capability for immediate examination of unexpected events.

2.4 CONTROLS

Control of the J-2S engine, battleship stage, and test cell systems during the terminal countdown was provided from the test cell control room. A facility control logic network was provided to interconnect the engine control system, major stage systems, the engine safety cutoff system, the observer cutoff circuits, and the countdown sequencer. A schematic of the engine start control logic is presented in Fig. 6. The sequence of engine events for start and shutdown is presented in Fig. 7. The engine control system was modified for this series of tests to simulate a full-face oxidizer flow injector configuration and to allow the transition to high thrust idle-mode operation without utilizing a solid-propellant turbine starter.

This modification required the main oxidizer valve be opened to its first-stage position during idle-mode operation by initiating main-stage start signal 1 sec after engine start signal and electrically preventing the hot gas tapoff valve from opening. High thrust idle mode was initiated by opening the hot gas tapoff valve.

SECTION III
PROCEDURE

Preoperational procedures were begun several hours before the test period. All consumable storage systems were replenished; and engine inspections, leak checks, and drying procedures were conducted. Propellant tank pressurants, engine pneumatic, and purge gas samples were taken to ensure that specification requirements were met. Chemical analysis of propellants was provided by the propellant suppliers. Facility sequence, engine sequence, and engine abort checks were conducted within a 24-hr time period before an engine firing to verify the proper sequence of events. Facility and engine sequence checks consisted of verifying the timing of valves and events to be within specified limits; the abort checks consisted of electrically simulating engine malfunctions to verify the occurrence of an automatic engine cutoff signal. A final engine sequence check was conducted immediately preceding the test period.

Oxidizer injector and thrust chamber jacket purges were initiated before evacuating the test cell. After completion of instrumentation calibrations at atmospheric conditions, the solid-propellant turbine starters were installed (test 04, only), the test cell was evacuated to approximately 0.5 psia with the exhaust machinery, and instrumentation calibrations at altitude conditions were conducted. Immediately before loading propellants on board the vehicle, the cell and exhaust-ducting atmosphere was inerted. At this same time, the cell nitrogen purge was initiated for the duration of the test period, except for engine main-stage and high thrust operation. The vehicle propellant tanks were then loaded, and the remainder of the terminal countdown was conducted. Temperature conditioning of the various engine components was accomplished as required, using the facility-supplied engine component conditioning system. Table V presents the engine purges and thermal conditioning operations during the terminal countdown and immediately following the engine firing.

SECTION IV
RESULTS AND DISCUSSION

4.1 TEST SUMMARY

Five firings of the Rocketdyne J-2S rocket engine were conducted during test periods J4-1001-04 and J4-1001-05 on July 17 and 29, 1969, respectively. Pressure altitude at engine start signal for these firings ranged from 85,000 to 101,000 ft.

The objectives for test period 04 were to (1) determine if main-stage conditions which existed during sea-level testing of engine S/N J-113 would result in similar abnormal oxidizer dome vibrations in the range of 4400 to 4700 Hz, (2) investigate oxidizer pump chilldown characteristics with an initially warm pump (-100°F), and (3) obtain performance data with the injector from engine S/N J-113. The primary objectives for test period 05 were to evaluate high thrust idle-mode operation with reduced oxidizer system resistance (simulating a full-face oxidizer flow injector configuration) and document effect of the thrust chamber bypass valve closing during high thrust idle mode. A summary of significant test variables and results is presented on the following page.

Firing J4-1001-	04A	04B	05A	05B	05C
Fuel pump inlet pressure at engine start signal, psia	33.6	32.9	33.2	40.3	33.1
Oxidizer pump inlet pressure at engine start signal, psia	39.4	37.8	38.6	32.8	38.5
Main oxidizer valve first-stage position, deg	12.5	12.5	13.5	13.5	13.5
Oxidizer idle-mode line orifice diameter, in.	Open	Open	0.500	0.500	0.500
Stabilized main-stage operation achieved	Yes	No	*	*	*
Stabilized-high thrust idle-mode operation achieved	**	**	No	No	No

*Main-stage operation was not a requirement for this test.
**High thrust idle-mode operation was not a requirement for this test.

Test requirements and specific test results are summarized in Table VI. Start and shutdown transient operating times for selected engine valves are presented in Table VII. Figure 8 shows the engine start conditions for the propellant pump inlets and the helium tank. Engine ambient and combustion chamber pressures, thrust chamber and fuel injector chilldown behavior, engine propellant flow rates and mixture ratios, propellant feed system performance, and turbine system temperatures are presented in Figs. 9 through 34. Also presented in these figures are the solid-propellant turbine starter chamber pressures for the applicable firings.

Data presented in the subsequent sections are from the digital data acquisition system, except where indicated otherwise. Propellant flow rates are based on pump discharge temperatures and pressures and on engine flowmeter calibration constants supplied by the engine manufacturer (5.50 and 2.00 cycles/gal for the oxidizer and fuel flowmeters, respectively).

4.2 TEST RESULTS

4.2.1 Firing J4-1001-04A

The objectives of this firing were to determine if main-stage conditions which existed during sea level testing of engine S/N J-113 would result in similar abnormal oxidizer dome vibrations (above 100 g rms) in the 4400- to 4700-Hz frequency range during altitude testing of engine J-112-1E and to obtain performance data with the

injector assembly from engine S/N J-113. Main-stage operation was successfully accomplished over the full range of propellant utilization valve positions. Performance data were obtained and are presented in Section 4.3. Oxidizier dome vibration data were recorded and analyzed. Abnormal vibrations (above 100 g rms) in the 4400- to 4700-Hz frequency range were not observed at the oxidizer dome. A further discussion of this test objective is presented in Section 4.3.

4.2.2 Firing J4-1001-04B

The objective of this firing was to investigate oxidizer pump chilldown characteristics during idle-mode operation with an initially warm pump bearing coolant cavity temperature of -107°F. Both the fuel and oxidizer pumps were warm at t-0 - 10 sec; the fuel pump balance piston sump temperature was -132°F at this time. The stage prevalves were opened at t-0 - 5 sec. Figure 35 shows the temperature behavior of the fluid inside the oxidizer pump bearing coolant cavity throughout the firing. After approximately 36.4 sec of low thrust idle-mode operation, liquid conditions were present in the bearing coolant cavity. This firing was terminated prematurely after 1.5 sec of main-stage operation by the automatic vibration safety cutoff system, precluding further oxidizer pump evaluation on this firing (Ref. Section 4.4).

4.2.3 Firing J4-1001-05A

The objectives of this firing were to evaluate high thrust idle-mode operation with (1) reduced oxidizer system resistance and (2) the thrust chamber bypass valve closing during high thrust idle-mode operation. The reduction of the oxidizer system resistance was accomplished by increasing the main oxidizer valve first-stage position from approximately 12.5 to 13.5 deg, which simulated a full-face oxidizer flow injector configuration. The firing was erroneously terminated after only 1.3 sec of high thrust idle-mode operation (t-0 + 4.5 sec) by an automatic monitor, because the indicated fuel turbine inlet temperature monitored by the engine safety cutoff system exceeded the safety limit of 1200°F (Ref. Section 4.5). Firing duration was insufficient for evaluation of high thrust idle-mode operation.

4.2.4 Firing J4-1001-05B

The objectives of this firing were the same as those of firing 05A, except the low thrust idle-mode duration was increased to 7 sec. The targeted pump inlet pressures were changed from 33 to 40 psia for the fuel pump and from 40 to 33 psia for the oxidizer pump. Both the increased low thrust idle-mode duration and the altered pump inlet pressures were utilized as an attempt to reduce the abnormally high temperatures obtained during firing 05A at the fuel turbine inlet and the hot gas tapoff manifold (Ref. Section 4.5).

Stabilized high thrust idle-mode operation was not attained during this firing, as may be noted in Fig. 25. The effects of closing the thrust chamber bypass valve during high thrust idle-mode operation could not be satisfactorily evaluated since stabilized high thrust idle-mode operation was not attained. Throughout high thrust idle mode,

significant vibration was detected at the oxidizer pump inlet duct (Ref. Section 4.6). A further discussion of high thrust idle-mode operation on this firing is presented in Section 4.5.

4.2.5 Firing J4-1001-05C

The objectives of this firing were the same as those of firing 05A, except the low thrust idle-mode duration was extended to 7 sec. The effects of the extended low thrust idle-mode duration on hot gas tapoff manifold and fuel turbine inlet temperatures during the transition into high thrust idle mode are discussed in Section 4.5.

Steady-state high thrust idle-mode operation was not attained during this firing (Fig. 30); therefore, the effects of closing the thrust chamber bypass valve during high thrust idle-mode operation could not be satisfactorily evaluated. A discussion of engine operation during high thrust idle mode is presented in Section 4.5. Throughout high thrust idle mode, significant vibration was detected at the oxidizer pump inlet duct (Ref. Section 4.6).

4.3 ENGINE VIBRATION, FIRING 04A

Abnormally high vibration levels were observed on engine S/N J-113 by the engine manufacturer during main-stage testing at sea-level conditions. Vibrations with amplitudes to 140 g rms over the 4400- to 4700-Hz frequency range were recorded at the oxidizer dome. The amplitudes varied with propellant utilization valve position, the highest with the valve open, and the lowest with it closed. The injector was thought to be the source of this vibration.

Firing 04A was conducted to determine if similar abnormal oxidizer dome vibrations would be encountered during main-stage testing of engine S/N J-112-1E, utilizing the injector assembly from engine S/N J-113, at simulated altitude conditions. The effect of propellant utilization valve position was examined according to the following schedule:

Time from Engine Start Signal, sec	Propellant Utilization Valve Position
0 to 6.4	Null
6.4 to 11.0	Closed
11.0 to 20.8	Null
20.8 to 34.2	Open

Power spectral density data (method of analysis, Appendix IV) Fig. 36, were reduced from oxidizer dome accelerometer, UTCD-4. Three 3-sec time periods, beginning at 7, 17, and 29 sec after engine start signal, were chosen for vibration data reduction to correspond with operation at the closed, null, and open propellant utilization valve positions, respectively. Vibration data were continuously recorded during main-stage operation.

Additional oxidizer dome vibration data were obtained and reduced from accelerometers UTCD-1 and UTCD-3. However, the outputs of these two accelerometers were conditioned in the engine vibration safety cutoff system (VSCS) which was shown, Fig. 37, to have a particularly degrading effect on accelerometer signal amplitude above 1000 Hz. Note in Fig. 37 that accelerometer UTCD-4 (which was not conditioned within the VSCS) produced an attenuation influence considerably different than either UTCD-1 or UTCD-3 in the 800- to 7000-Hz frequency range.

Although the abnormal 4400- to 4700-Hz vibration experienced at sea level was not encountered during firing 04A, a predominant frequency at each propellant utilization valve position was observed. Vibration amplitudes were small, less than 100 g rms. The basic engine performance associated with each propellant utilization valve position and observed engine vibration frequency are tabulated below. Performance data were calculated as shown in Appendix V.

Propellant utilization valve position	Closed	Null	Open
Predominant oxidizer dome vibration frequency, Hz	5900	5400	5400
Engine thrust, vacuum corrected, lbf	262,000	236,000	214,000
Engine mixture ratio, O/F	5.25	4.75	4.35
Engine total propellant flow rate, lbm/sec	606	541	488
Engine specific impulse, vacuum corrected, lbf-sec/lbm	432	436	437
Characteristic velocity, ft/sec	7670	7800	7870

The influence of the propellant utilization valve on oxidizer dome vibration was apparently insignificant. Although the predominant vibration frequency at the closed position was about 500 Hz higher than at the other two positions, the engine had not achieved steady-state operation at this time; the engine was operating steady state at the other two valve positions.

4.4 ABNORMAL TRANSITION TO MAIN STAGE DURING FIRING 04B

Firing 04B was programmed for 7.5 sec of main-stage operation; however, the firing was terminated prematurely after 1.47 sec of main-stage operation by the automatic vibration safety cutoff system. The cutoff limits were set for 70 msec of 150 g rms continuous vibration. A total of 340 msec of sporadic engine vibration in excess of

150 g rms was recorded, 110 msec of which occurred before the cutoff signal. From Fig. 38, it may be noted that the engine experienced an abnormal transition to main-stage operation. Combustion chamber pressure increased about 16 psi approximately 337 msec after the main-stage start signal. Also, at this time, there were temperature increases at the oxidizer and fuel injectors. The injection pressures increased, on the average, about 30 psi. There was no apparent damage to the engine.

4.5 HIGH THRUST IDLE MODE

Firing 05A was terminated prematurely after 1.3 sec of high thrust idle-mode operation. This resulted because of an erroneous indication that the fuel turbine inlet temperature, monitored by the engine safety cutoff system (ESCS) exceeded the established safe limit of 1200°F. Histories of the tapoff manifold and fuel turbine inlet temperatures during the transition to high thrust idle mode are shown in Fig. 24. (The turbine inlet temperature sensor shown in Fig. 24 is not monitored by the ESCS.) Peak temperatures recorded at engine cutoff signal were 1027 and 691°F for the hot gas tapoff manifold and fuel turbine inlet temperatures, respectively.

The low thrust idle-mode duration was increased from 3 to 7 sec for firings 05B and 05C. This allowed the propellant feed systems to chill sufficiently to reduce the transient chamber mixture ratios. The resulting peak hot gas tapoff manifold and fuel turbine inlet temperatures during transition to high thrust idle mode were 575 and 430°F, respectively, for firing 05B (Fig. 29), and 799 and 495°F, respectively, for firing 05C (Fig. 34).

A decay in high thrust idle-mode performance during previous J-2S engine testing at AEDC (Refs. 6 and 7) has been attributed to icing in either the fuel or oxidizer turbine. The presence of turbine icing was detected on previous tests by noting a decrease in pump speed, accompanied by an increase in turbine internal resistance.

Although transition was smooth, firing 05B did not achieve steady-state, high thrust, idle-mode operation. Firing J4-1902-16A (Ref. 2), which was a successful high thrust idle-mode firing, also had steady turbine pressure drop and speed during high thrust idle-mode operation. During firing 05B the turbine pressure drop and speed were relatively steady for both the oxidizer and fuel turbines with no apparent decay in performance after the initial 6 sec of high thrust idle-mode operation (Fig. 39). The fuel turbine speed gradually increased to approximately 15,600 rpm at engine cutoff signal. The oxidizer turbine exhibited a similar trend. Indicated turbine inlet and outlet temperatures were too warm for the formation of ice inside the fuel turbine after high thrust idle-mode initiation. However, the indicated oxidizer turbine outlet temperature was below 32°F during low thrust idle mode and for 3 sec after high thrust idle-mode initiation. The temperature increased to about 50°F 4 sec after initiation and then decreased to a low of about 35°F between 7 and 9 sec after high thrust idle-mode initiation. The temperature then continued to increase until engine cutoff signal at which time it was indicating approximately 85°F. Therefore, there is no indication of icing in either the oxidizer or fuel turbine.

Closing the fuel bypass valve during high thrust idle-mode operation, t-0 + 22.5 sec, resulted in a 65°F increase in fuel injection temperature (Fig. 26). Closing of fuel bypass valve coincided with the beginning of a steady increase in chamber pressure and propellant feed system pressures.

Firing 05C experienced severe performance degradation during high thrust idle-mode operation. After high thrust idle-mode initiation, and until about t-0 + 28 sec, there was a significant reduction in chamber pressure (Fig. 30), the propellant feed system pressures, and the pump speeds. Transition to high thrust idle mode was smooth and stable. Comparison of turbine performance with firing J4-1902-15C (Ref. 6), which is considered to have experienced oxidizer turbine icing, revealed that speed and pressure drop across the turbine were both decreasing (Fig. 40) during high thrust idle mode until about t-0 + 28 sec. This tended to discount turbine icing as the problem, for the internal resistance was decreasing as the turbine speed decreased. However, the oxidizer turbine back pressure (POTO, Fig. 40) was increasing as the other pressures were decreasing. This indicates that a flow restriction, possibly icing, existed downstream of the oxidizer turbine. At about t-0 + 28 sec, abnormal engine vibration, as measured by the engine vibration safety cutoff system, was recorded for about 110 msec, which exceeded 150 g rms. Also, at this time, chamber pressure, the propellant feed system pressures, and the turbine speeds began increasing. Stabilized engine operation appeared to have existed from t-0 + 30 sec until engine cutoff signal. The fuel bypass valve was initiated closed at t-0 + 22.5 sec, which resulted in an increase in fuel injection temperature of 65°F. Excessive engine ambient pressure and temperature during the firing prevented meaningful evaluation of engine performance.

4.6 OXIDIZER PUMP INLET VIBRATION

Throughout high thrust idle-mode operation of firings 05B and 05C, unusual vibration was detected at the oxidizer pump inlet duct with a frequency of approximately 16 Hz, the natural frequency of the duct. Vibration of the pump inlet bellows along its longitudinal axis was clearly evident in motion pictures of firing 05B, and exhibited an amplitude of approximately ±1 in. The vibration was also reflected in chamber pressure and most of the oxidizer system pressures, particularly oxidizer pump inlet pressure. It is suspected that the vibration was flow induced, possibly associated with inlet "pre-rotation" previously noted when operating the engine in high thrust idle mode (Ref. 7).

4.7 INJECTOR SEAL FAILURE

Following test period J4-1001-05, the injector assembly was removed from the engine for installation of the full-face oxidizer flow injector scheduled for testing during test period J4-1001-06. It was discovered that the injector stainless steel ring seal (P/N 18781-9-7) had failed. The location of the seal in relation to the injector assembly may be seen in Fig. 5d, and photographs of the seal are shown in Fig. 41. It is not known when the seal failed or the effect of this failure on engine operation. However, if the failure point on the seal were located within close proximity to a hot gas tapoff port, raw fuel could have entered the tapoff manifold during engine operation.

SECTION V
SUMMARY OF RESULTS

The results of the five firings of the J-2S rocket engine S/N J-112-1E during test periods J4-1001-04 and 05 are summarized as follow:

1. Main-stage operation of engine S/N J-112, utilizing the injector assembly from engine S/N J-113, exhibited no abnormal (above 100 g rms) oxidizer dome vibrations. Predominant frequencies in the range of 5400 to 5900 Hz were recorded; propellant utilization valve position had an insignificant effect on the vibration level.

2. Forty seconds of low thrust idle-mode operation during firing 04B was found to be sufficient for producing liquid temperature throughout the oxidizer pump with an initial temperature inside the pump of -107°F.

3. Abnormal chamber pressure increases were recorded during transition to main stage of firing 04B, resulting in a premature engine cutoff by the vibration safety cutoff system.

4. Stabilized high thrust idle mode on two firings within this series was not attained; idle-mode operation conditions inside the fuel and oxidizer turbines did not indicate the presence of icing.

5. Throughout high thrust idle-mode operation of firings 05B and 05C, the oxidizer pump inlet bellows vibrated along its longitudinal axis at a frequency of 16 Hz, with an amplitude of about ±1 in.

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3. "J-2S Interface Criteria." Rocketdyne Document J-7211, October 16, 1967.

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5. Test Facilities Handbook (Eighth Edition) (AD863646). "Large Rocket Facility, Vol. 3." Arnold Engineering Development Center, December 1969.

6. Kunz, C. H. and Counts, H. J., Jr. "Altitude Developmental Testing of the J-2S Rocket Engine in Rocket Development Test Cell (J-4) (Tests J4-1902-13 through J4-1902-15)." AEDC-TR-70-122, June 1970.

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APPENDIXES

I. ILLUSTRATIONS
II. TABLES
III. INSTRUMENTATION
IV. POWER SPECTRAL DENSITY WAVE ANALYSIS
V. METHOD OF CALCULATION

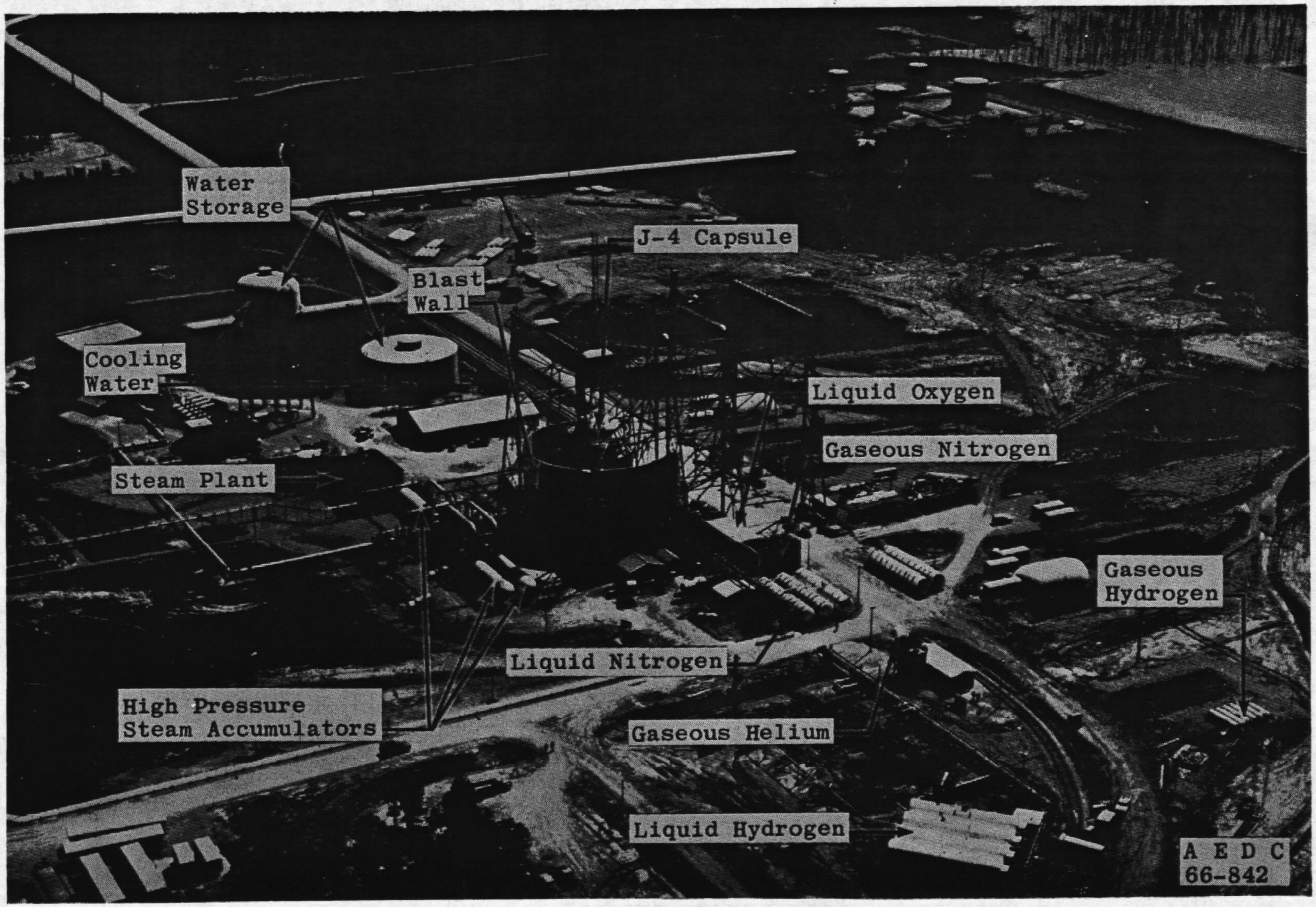


Fig. 1 Test Cell J-4 Complex

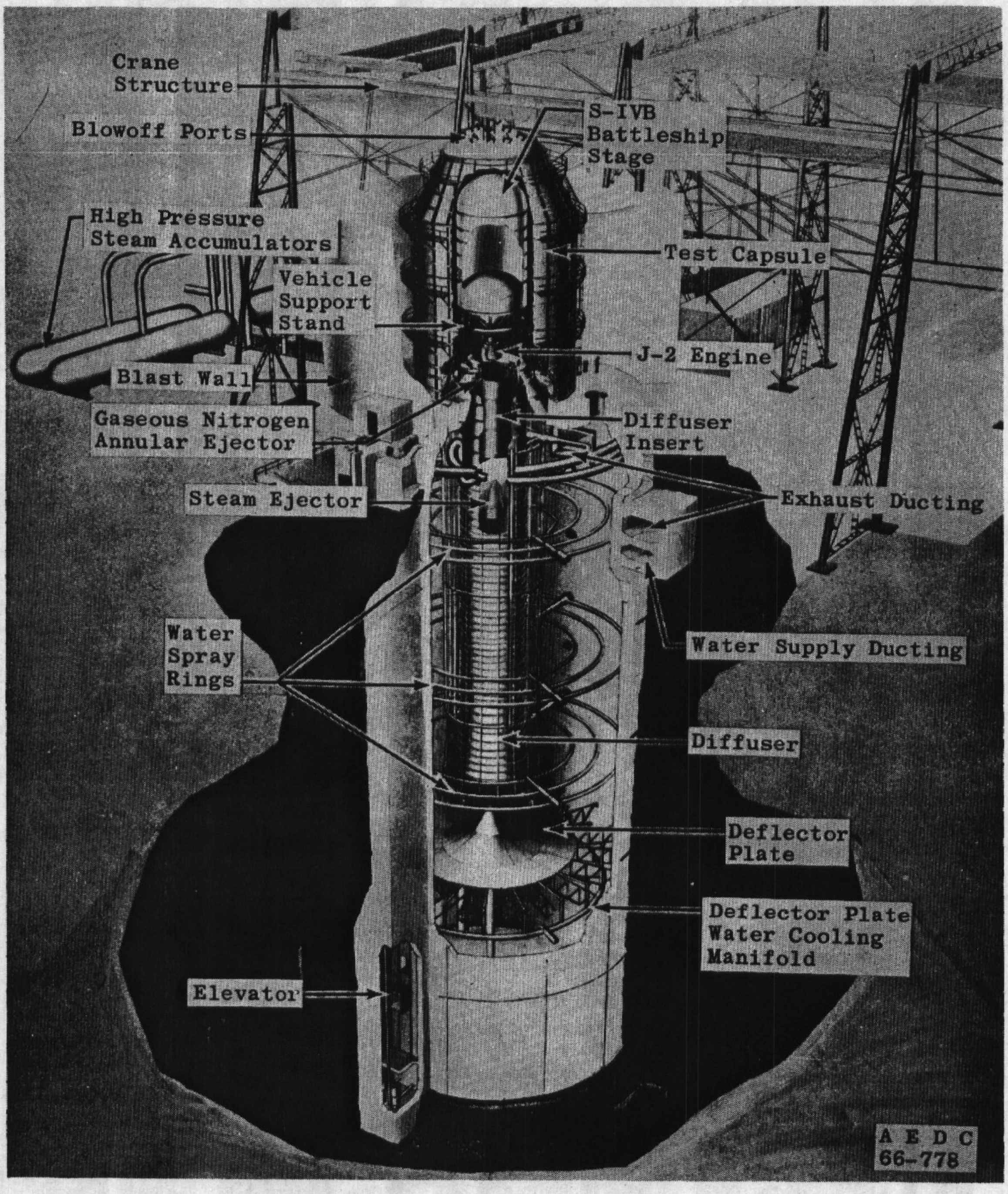


Fig. 2 Test Cell J-4, Artist's Conception

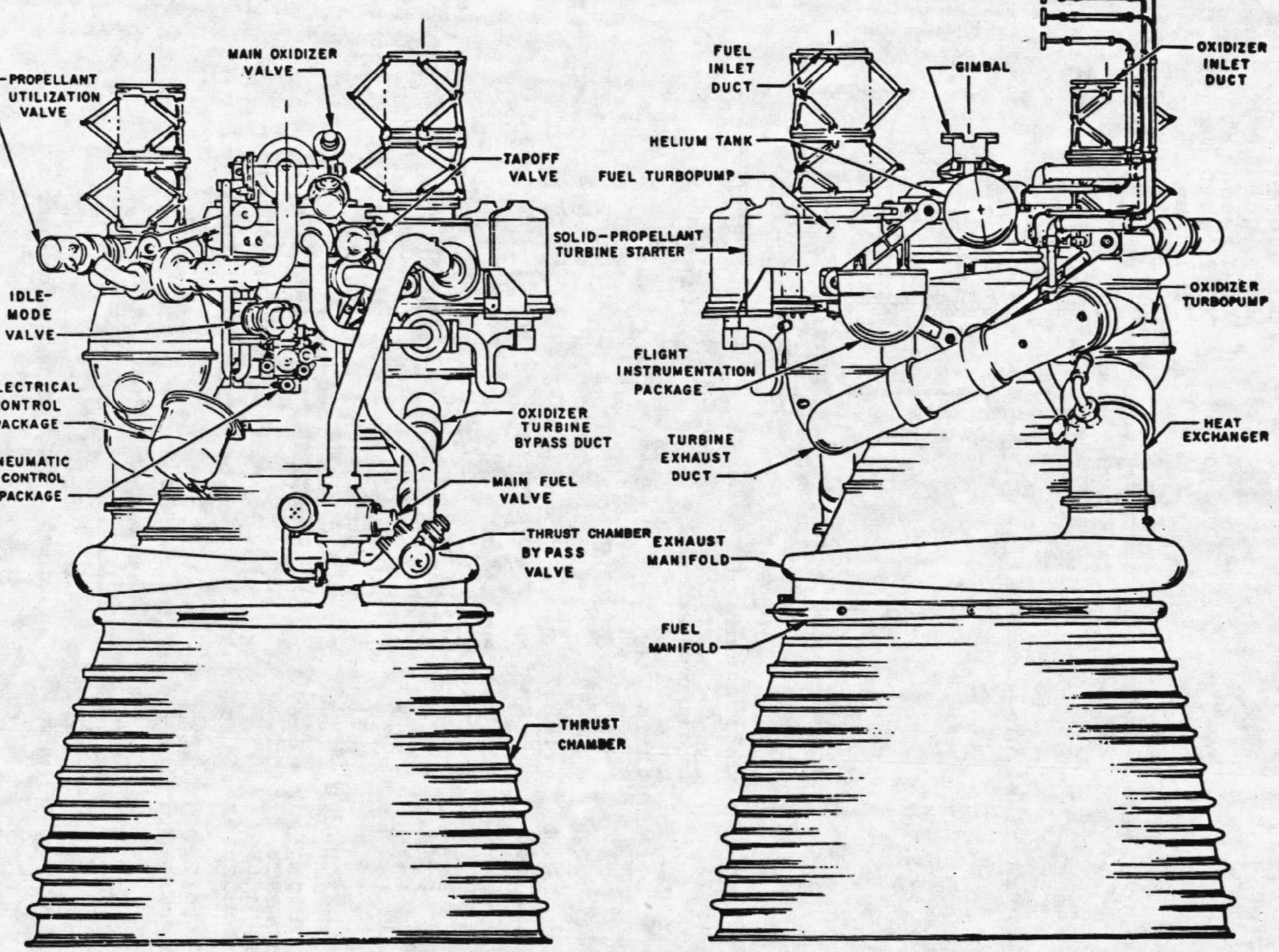


Fig. 3 J-2S Engine General Arrangement

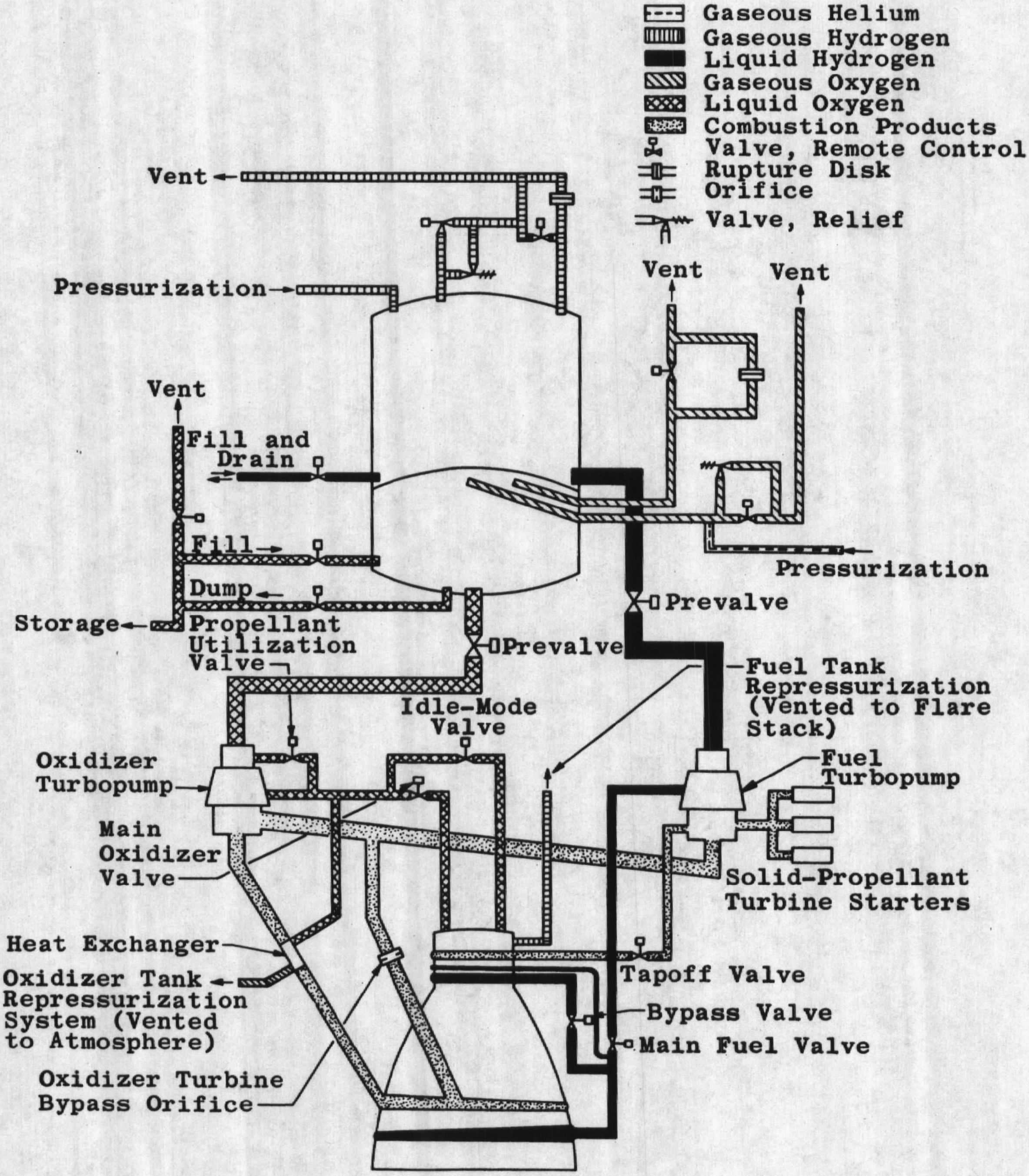
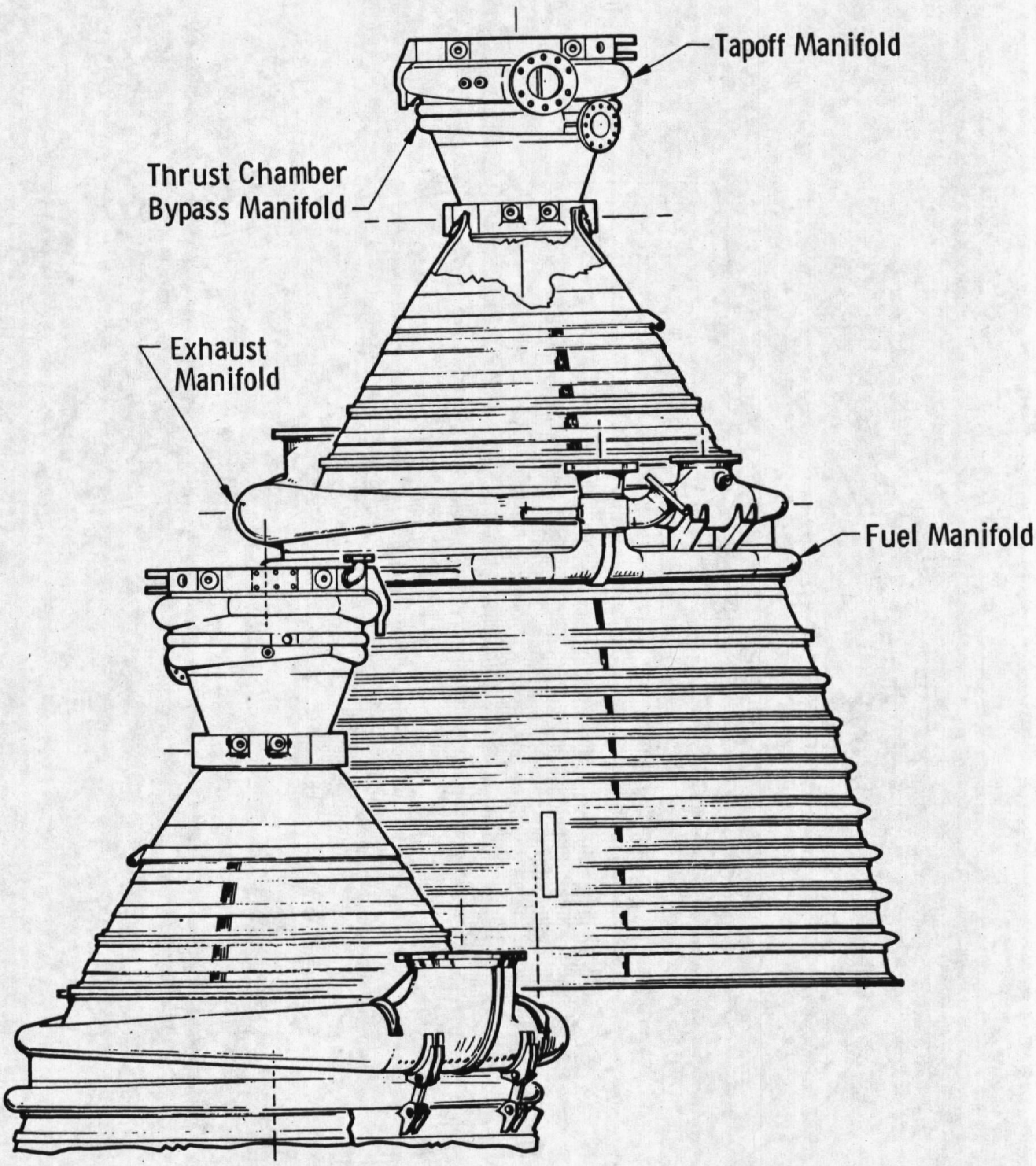
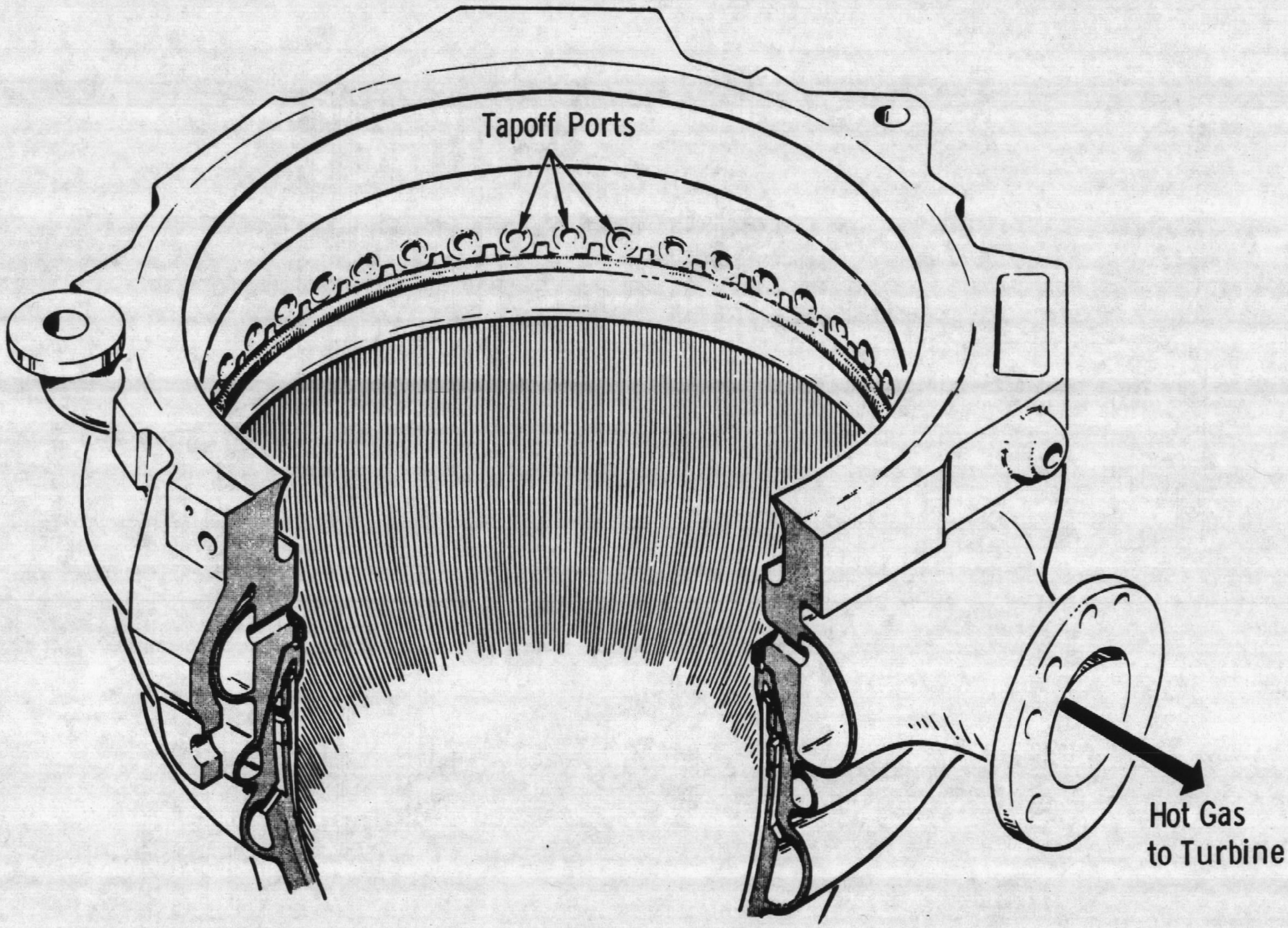


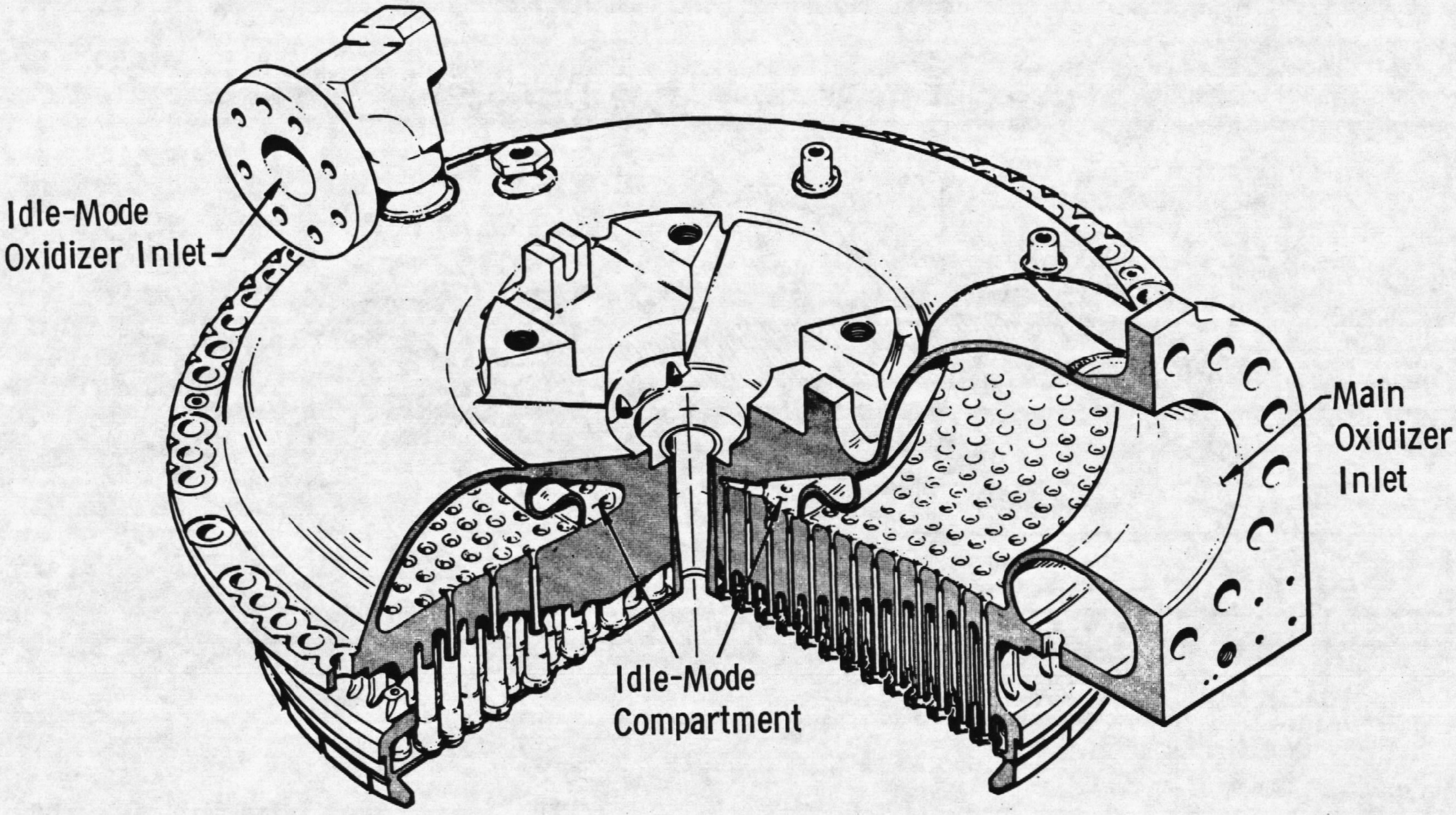
Fig. 4 S-IVB Battleship Stage/J-2S Engine Schematic



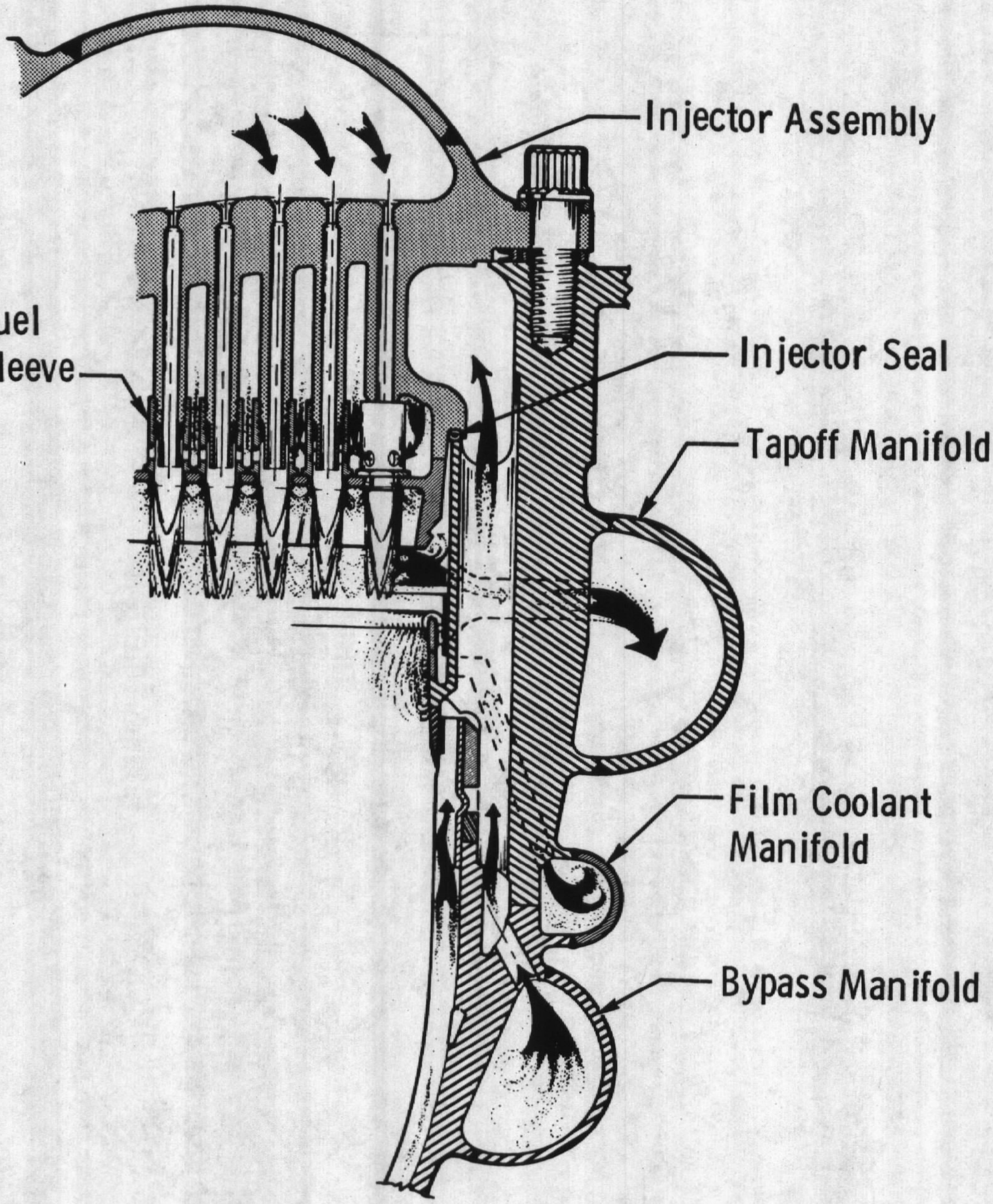
a. Thrust Chamber
Fig. 5 Engine Details



b. Combustion Chamber
Fig. 5 Continued

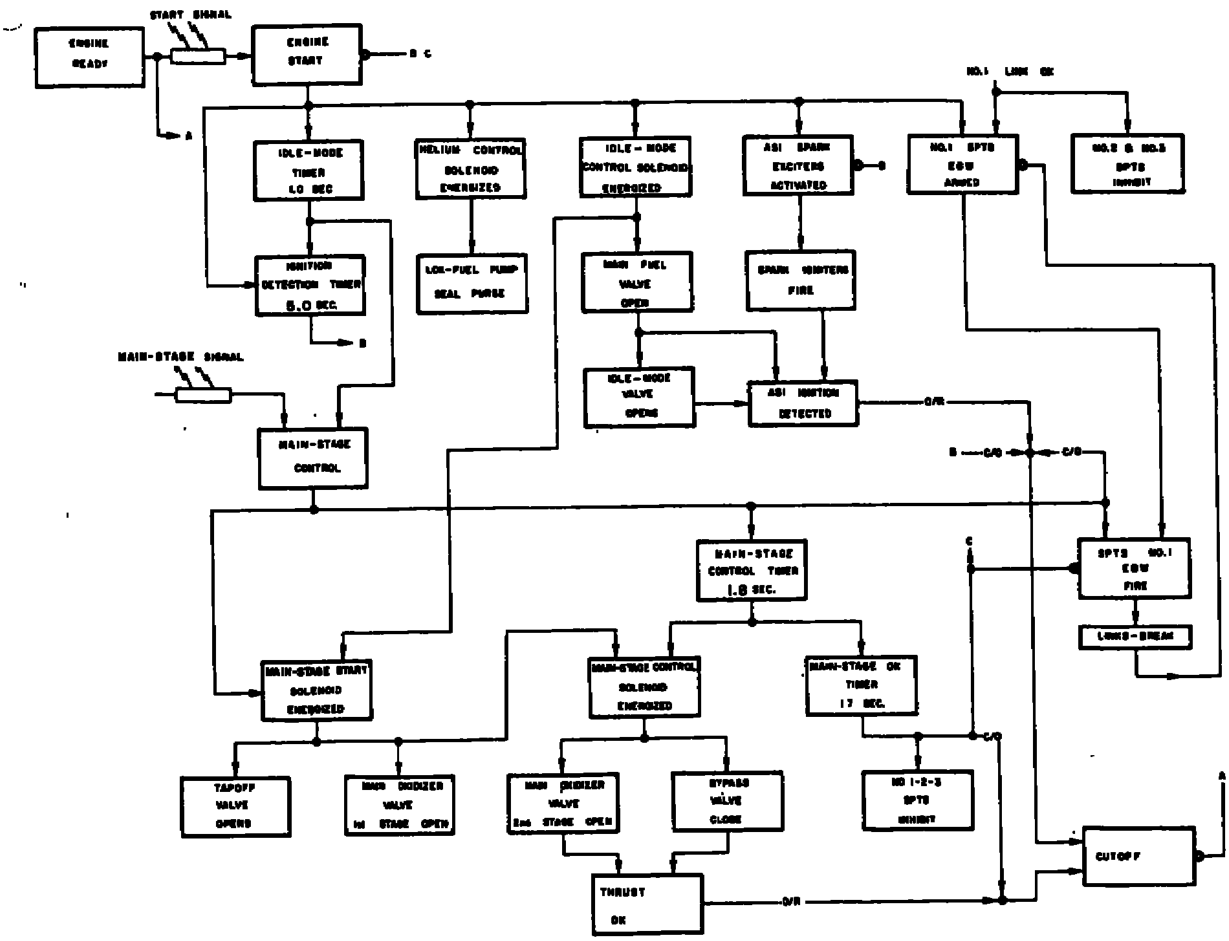


c. Injector
Fig. 5 Continued



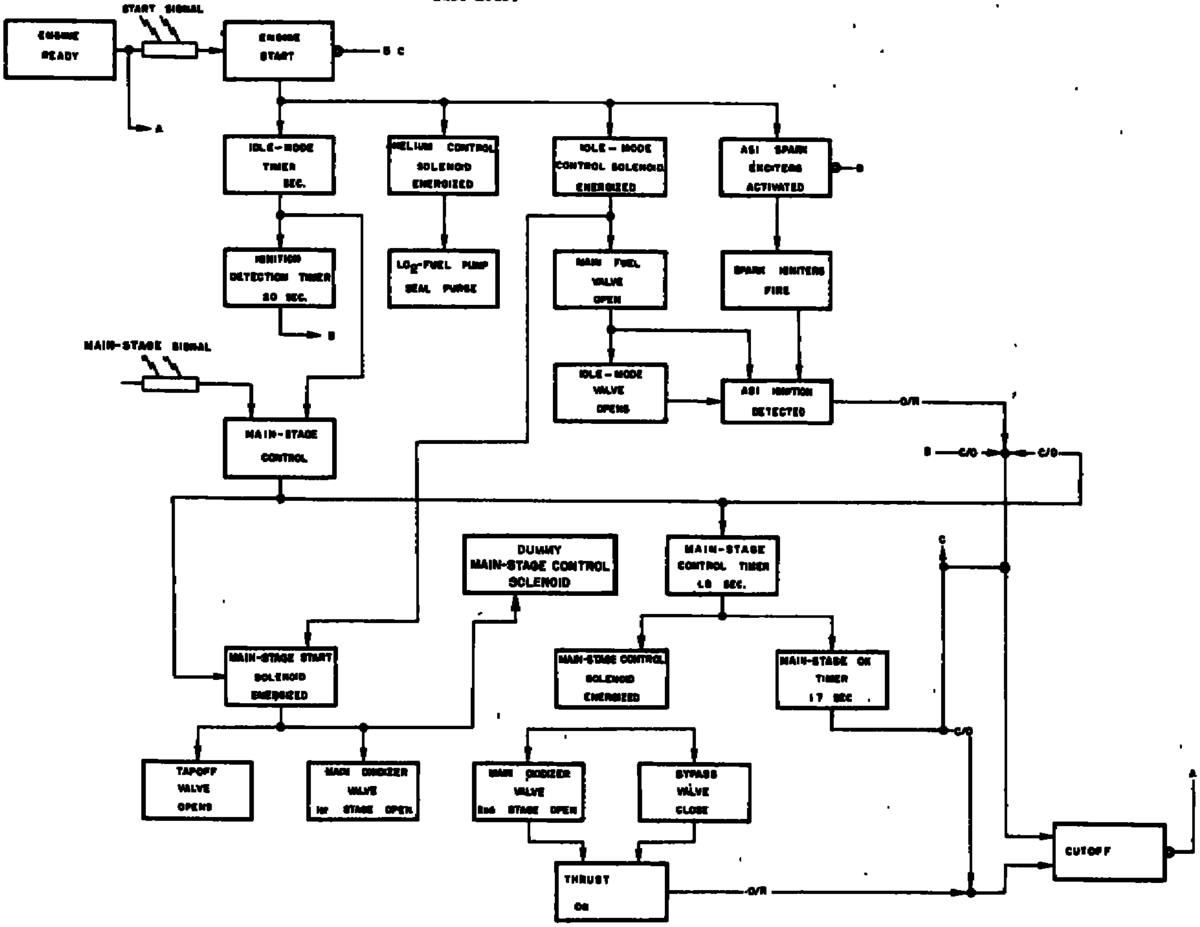
d. Injector to Chamber
Fig. 5 Concluded

Note: Idle-mode timer duration was 40.0 sec on Firing 04B.

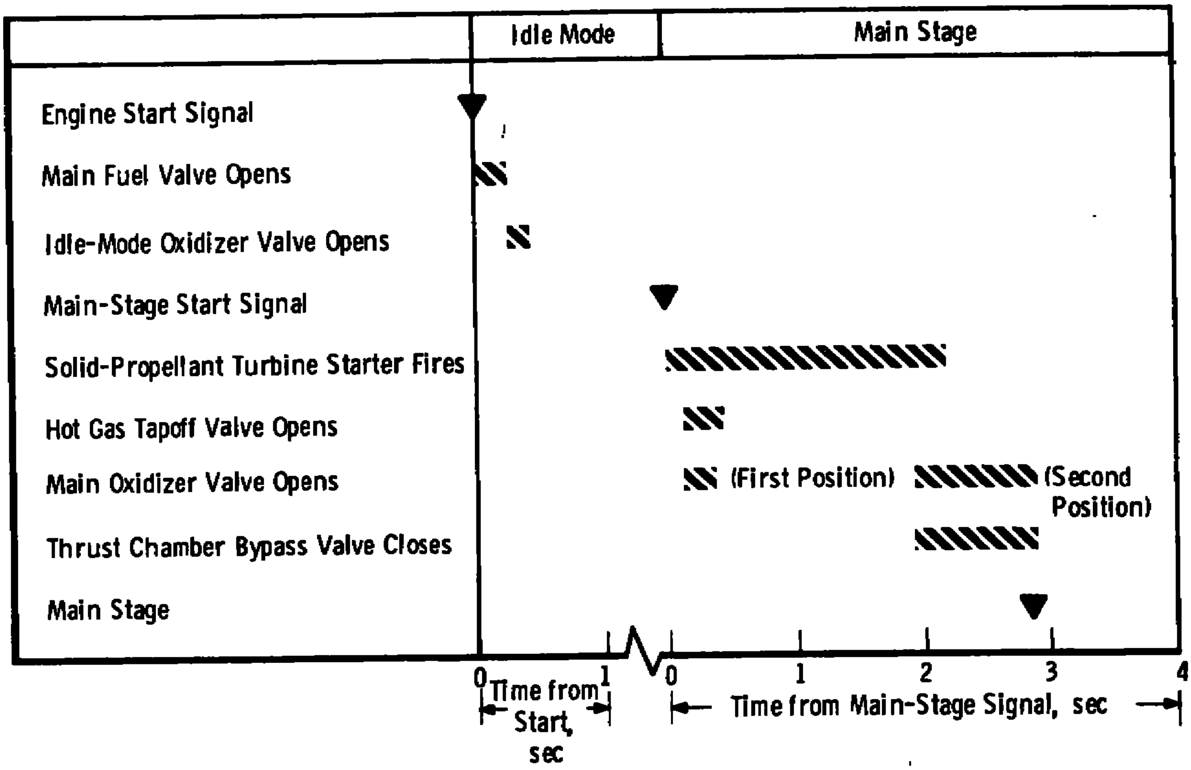


a. Firings 04A and 04B
Fig. 6 Engine Start Logic Schematic

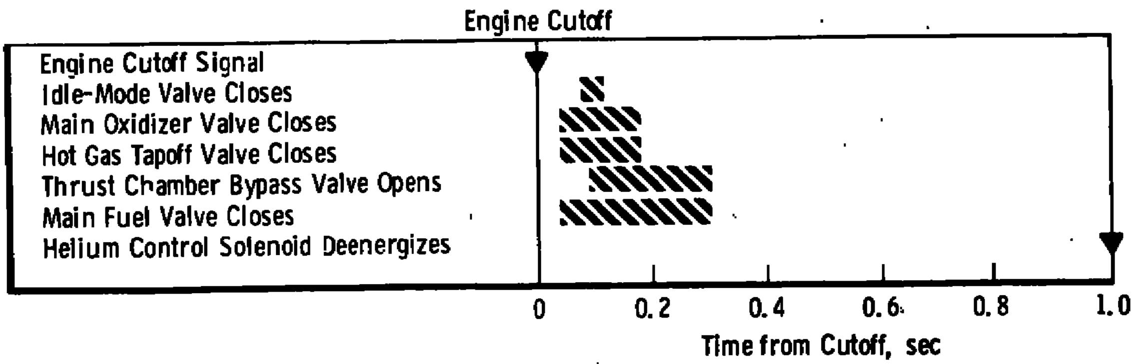
Notes: 1. The tapoff valve was operated manually on this test period.
2. Idle-mode timer duration was 3.0 sec for Firing 05A and 7.0 sec for Firings 05B and 05C.
3. The bypass valve was closed manually during high thrust idle mode.



b. Firings 05A, 05B, and 05C
Fig. 6 Concluded

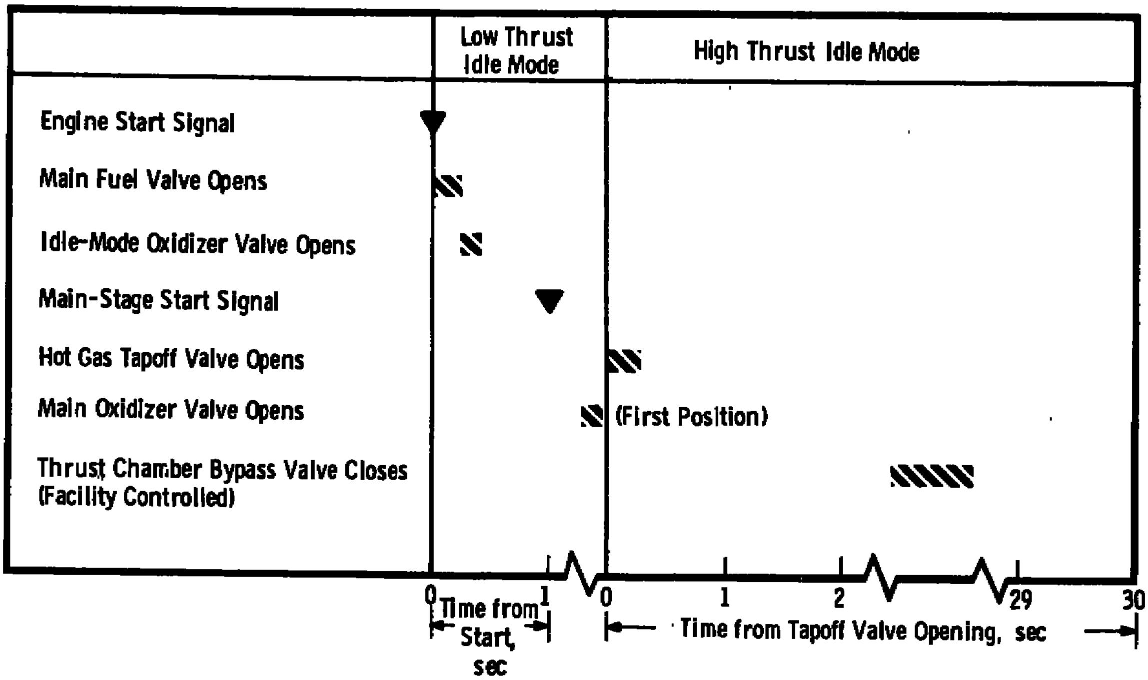


a. **Start, Test Period 04**

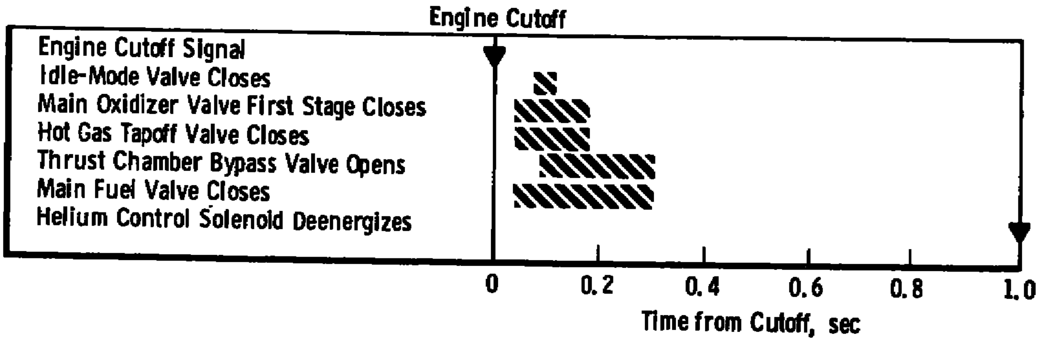


b. **Shutdown, Test Period 04**

Fig. 7 Engine Start and Shutdown Sequence

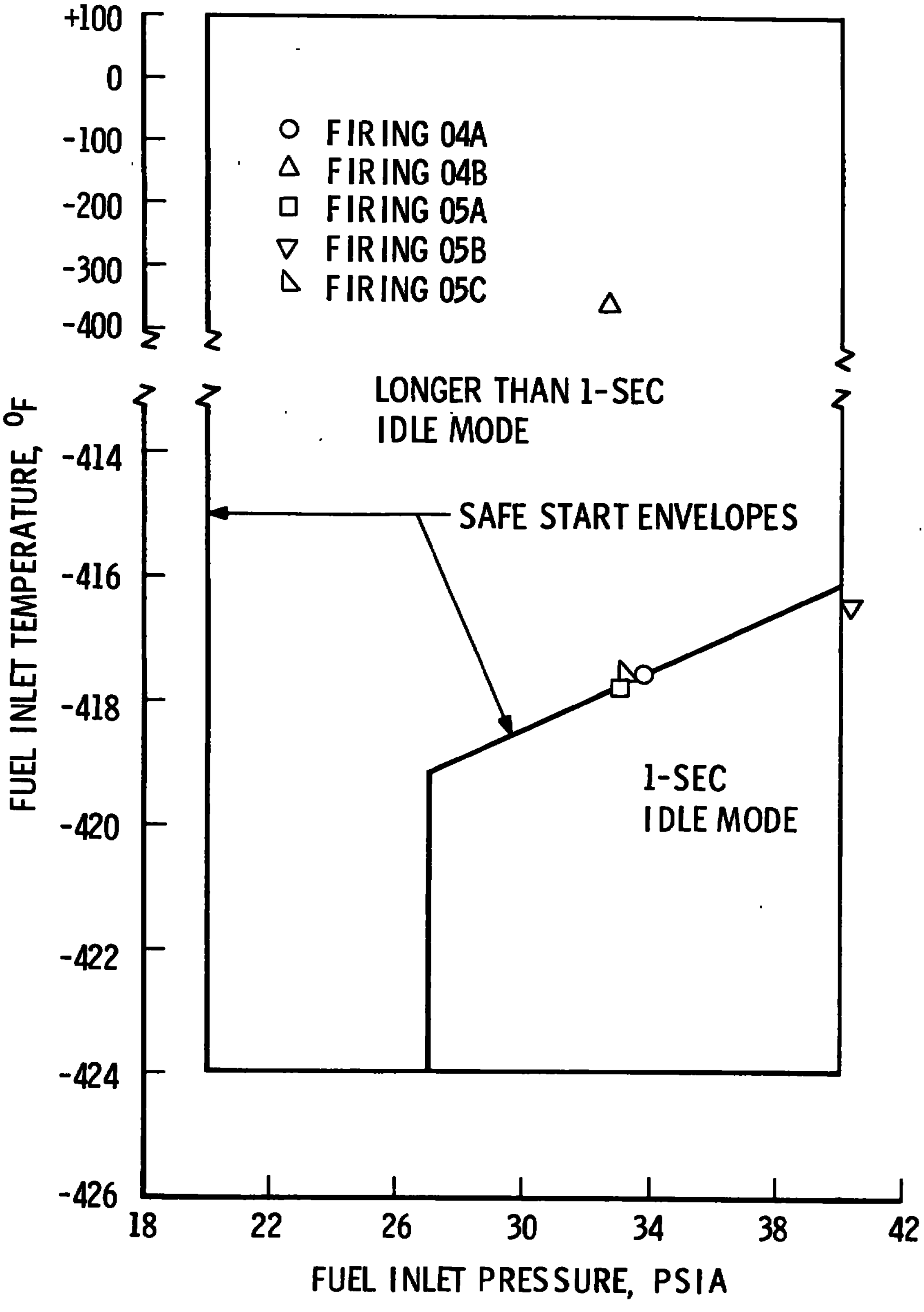


c. Start, Test Period 05



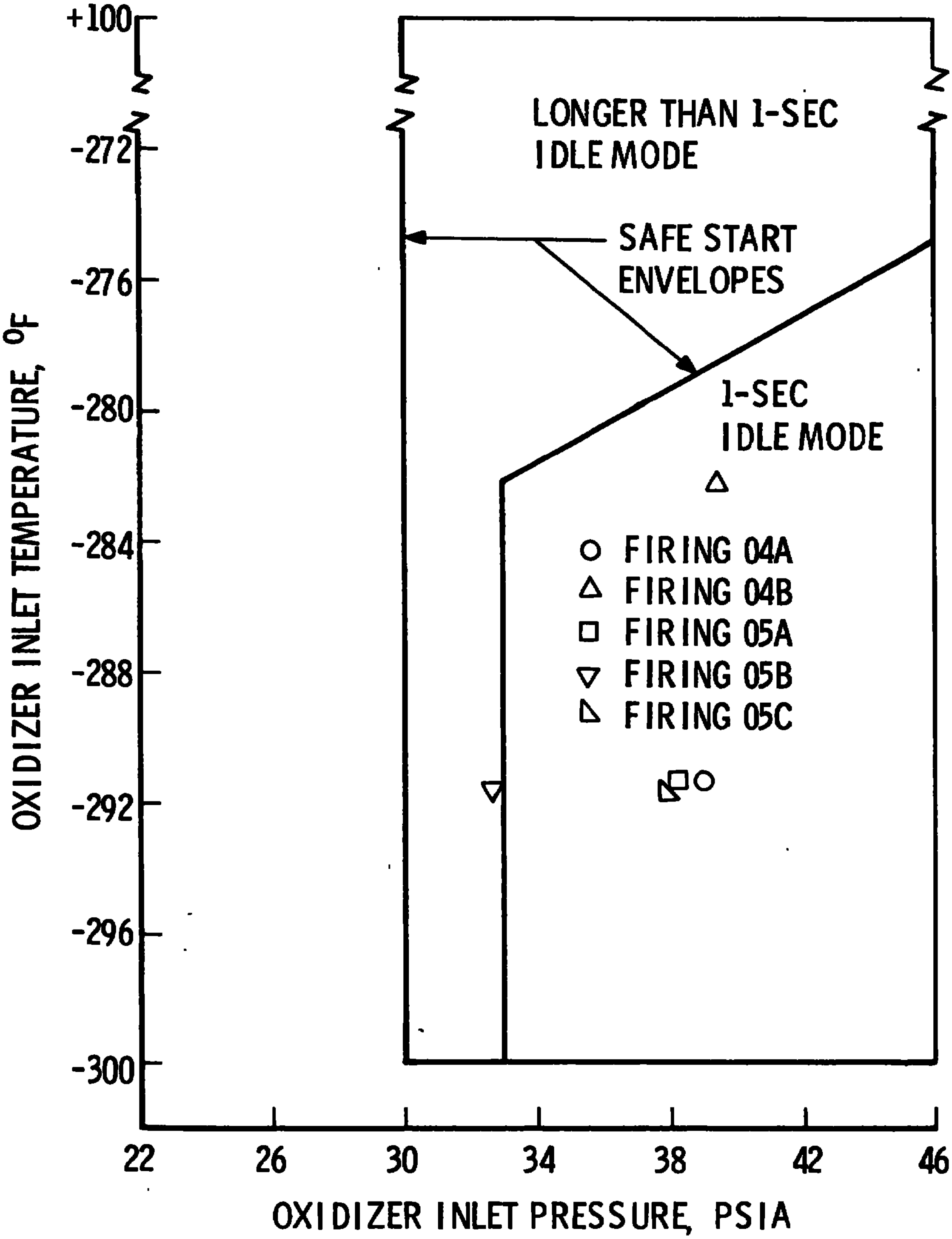
d. Shutdown, Test Period 05

Fig. 7 Concluded

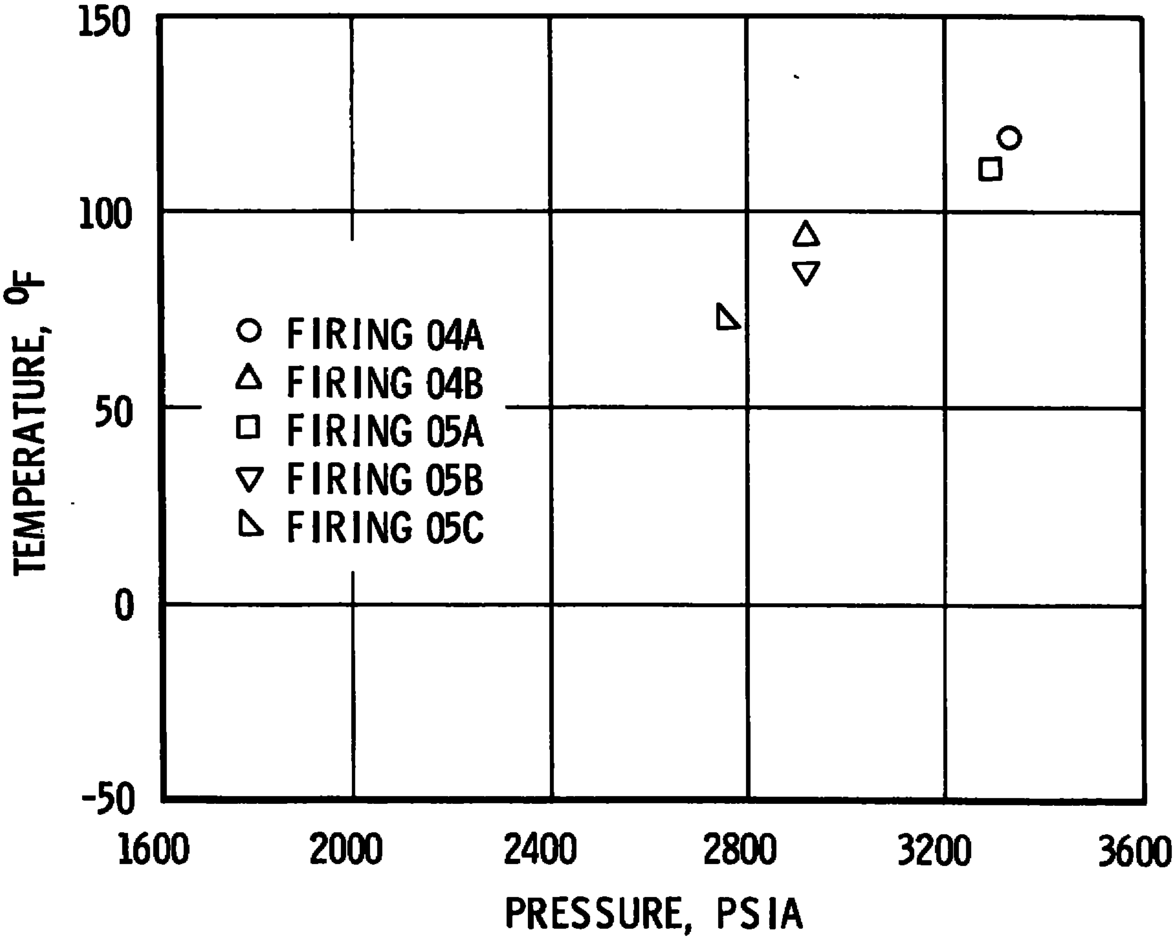


a. Fuel Pump

Fig. 8 Engine Start Conditions for Propellant Pump Inlets and Helium Tank



b. Oxidizer Pump
Fig. 8 Continued



c. Helium Tank
Fig. 8 Concluded

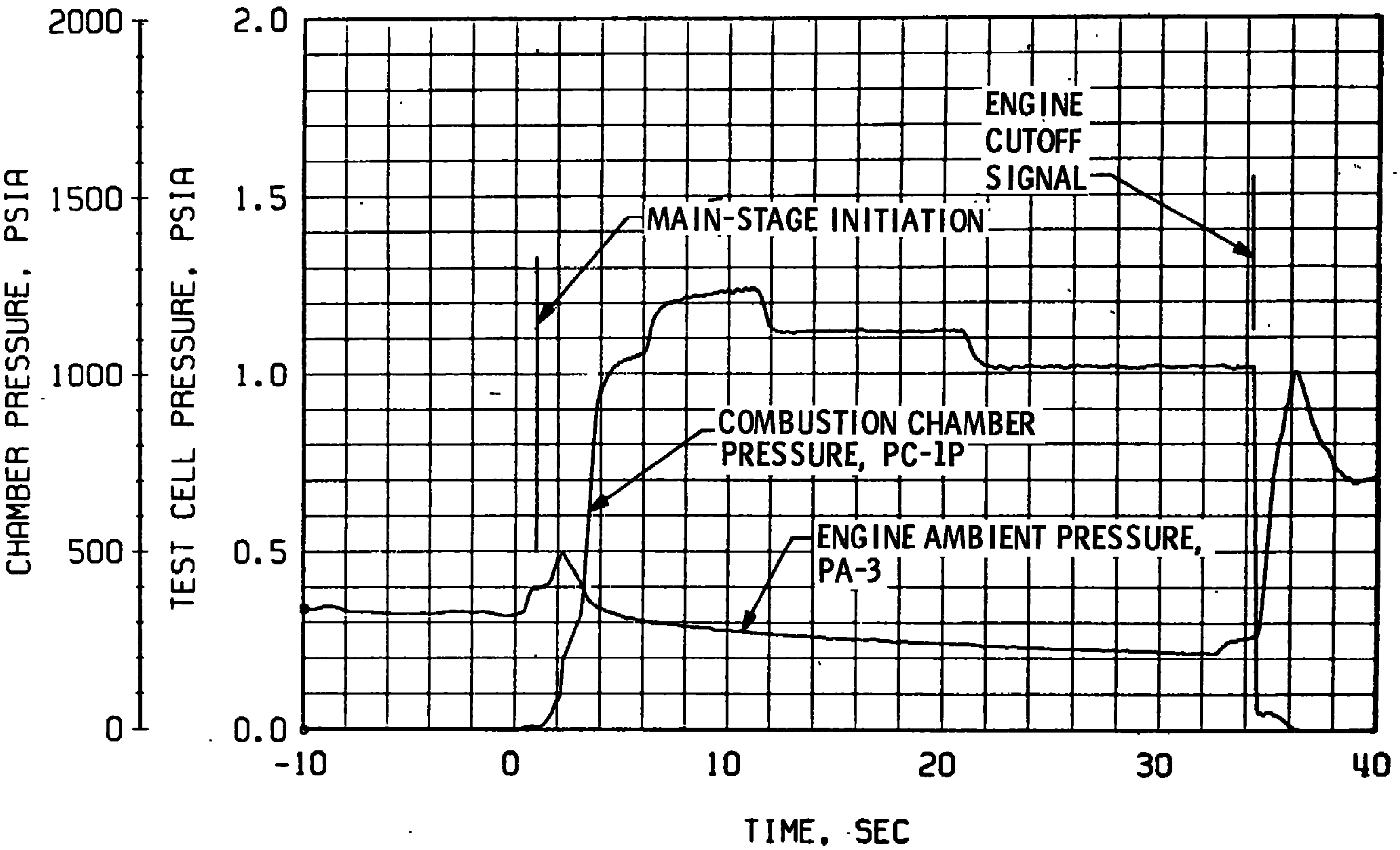


Fig. 9 Engine Ambient and Combustion Chamber Pressures, Firing 04A

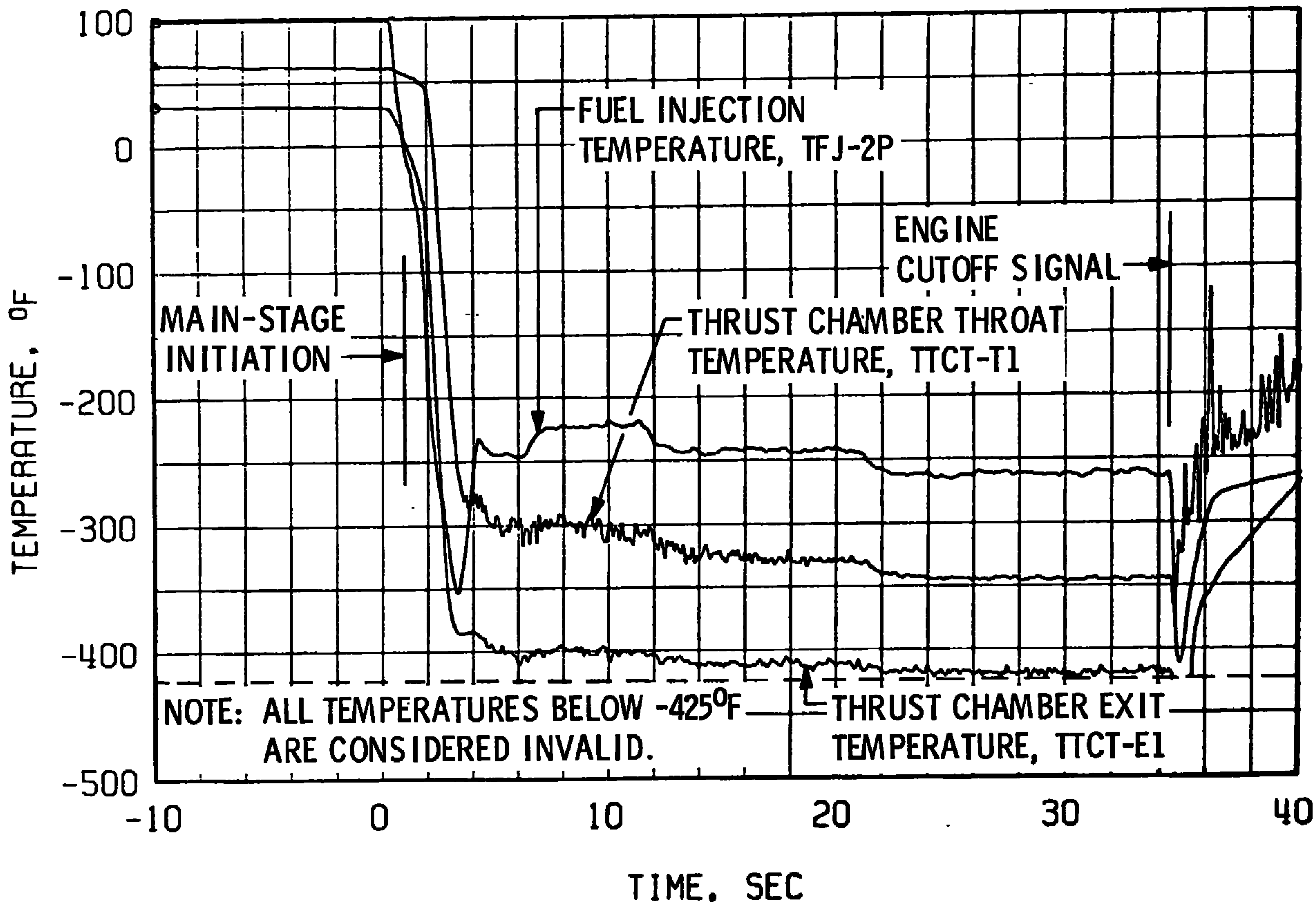


Fig. 10 Thrust Chamber Chilldown and Fuel Injection Temperature, Firing 04A

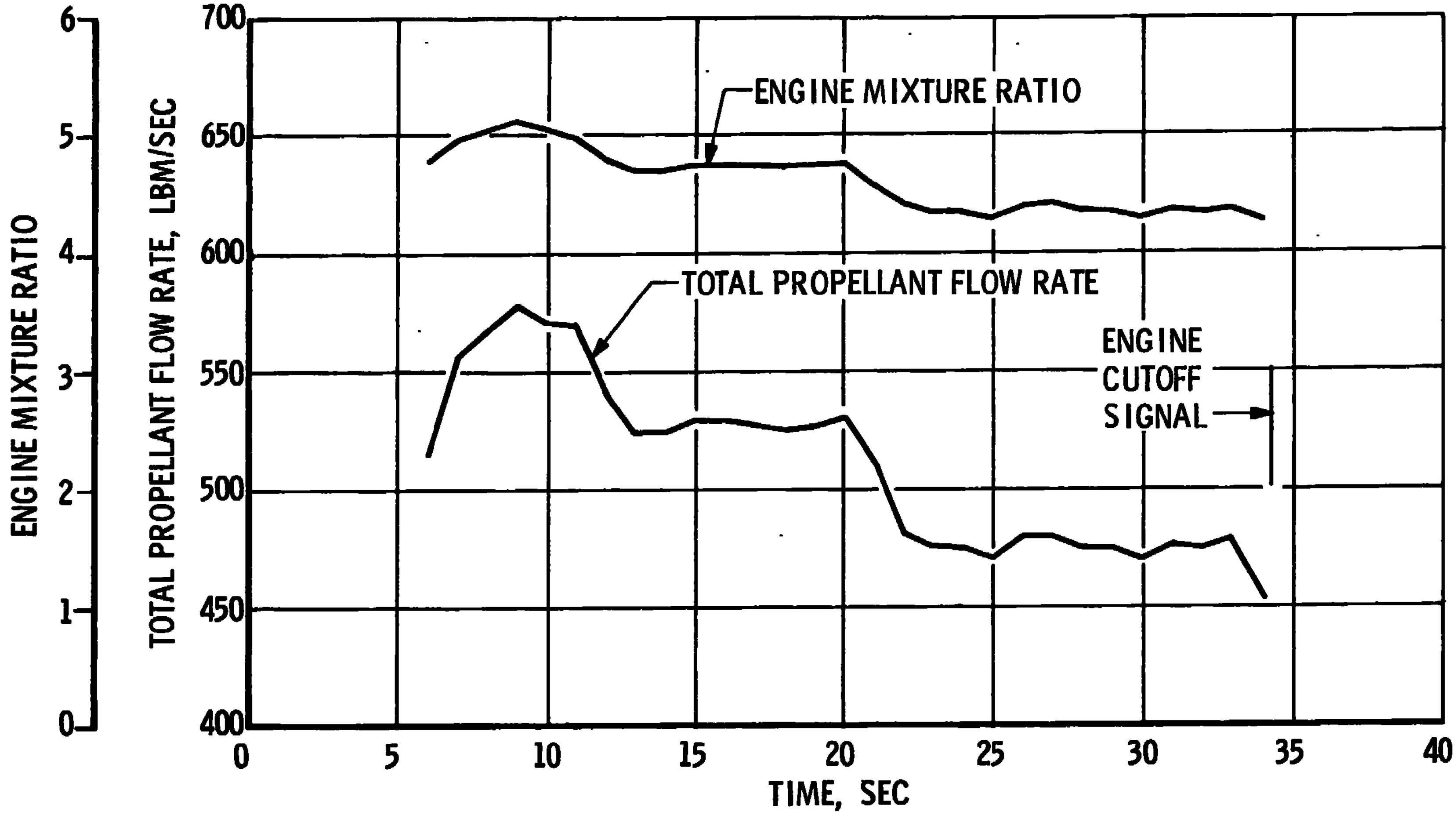


Fig. 11 Total Propellant Flow Rate and Engine Mixture Ratio, Firing 04A

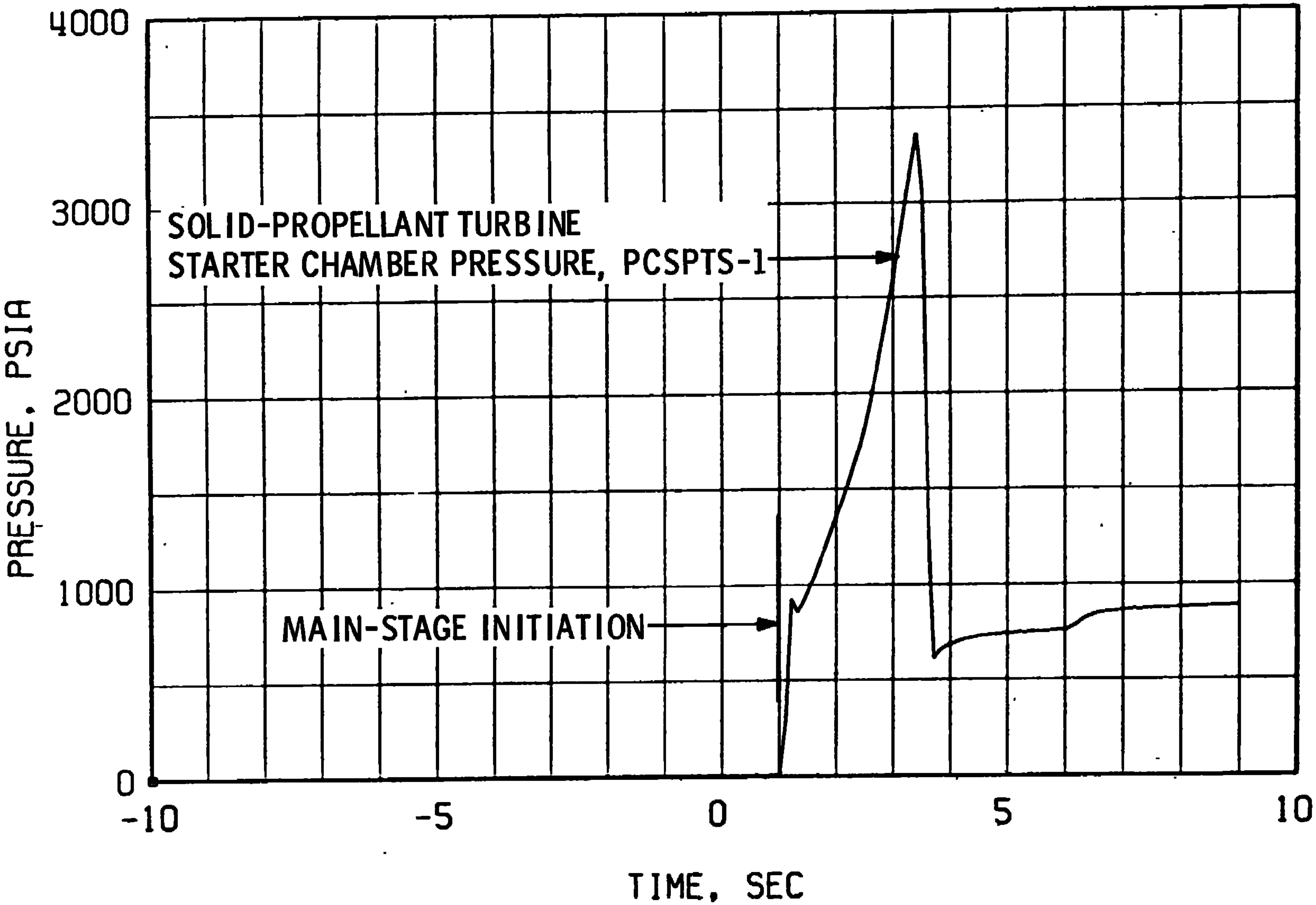
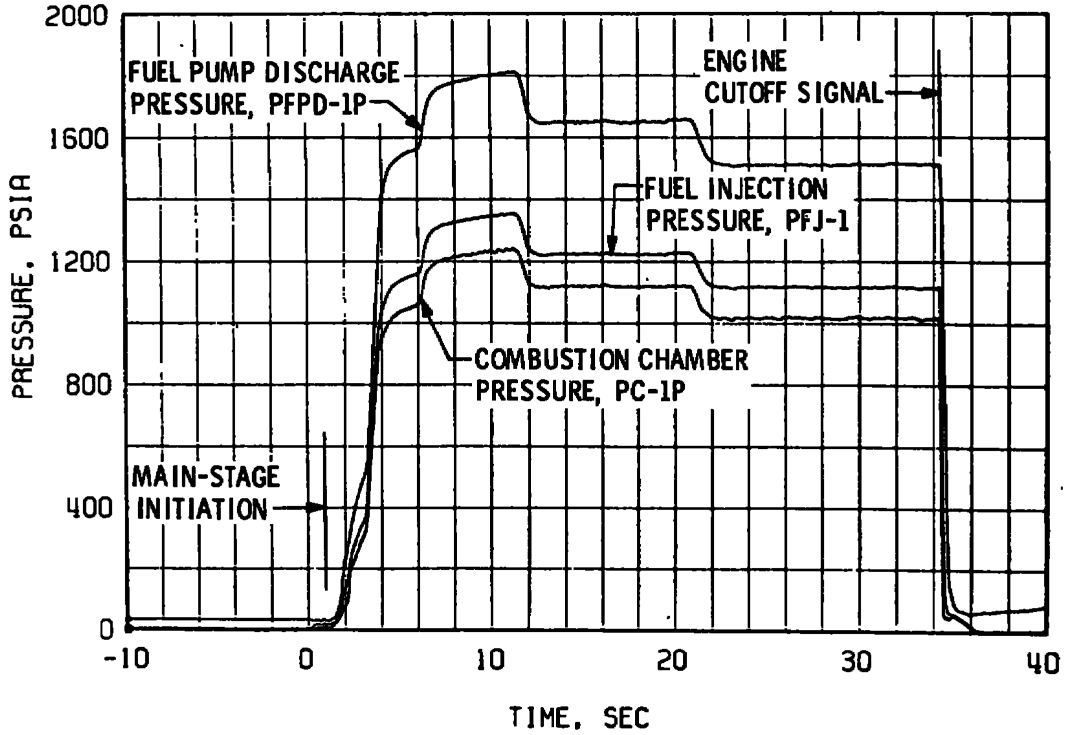
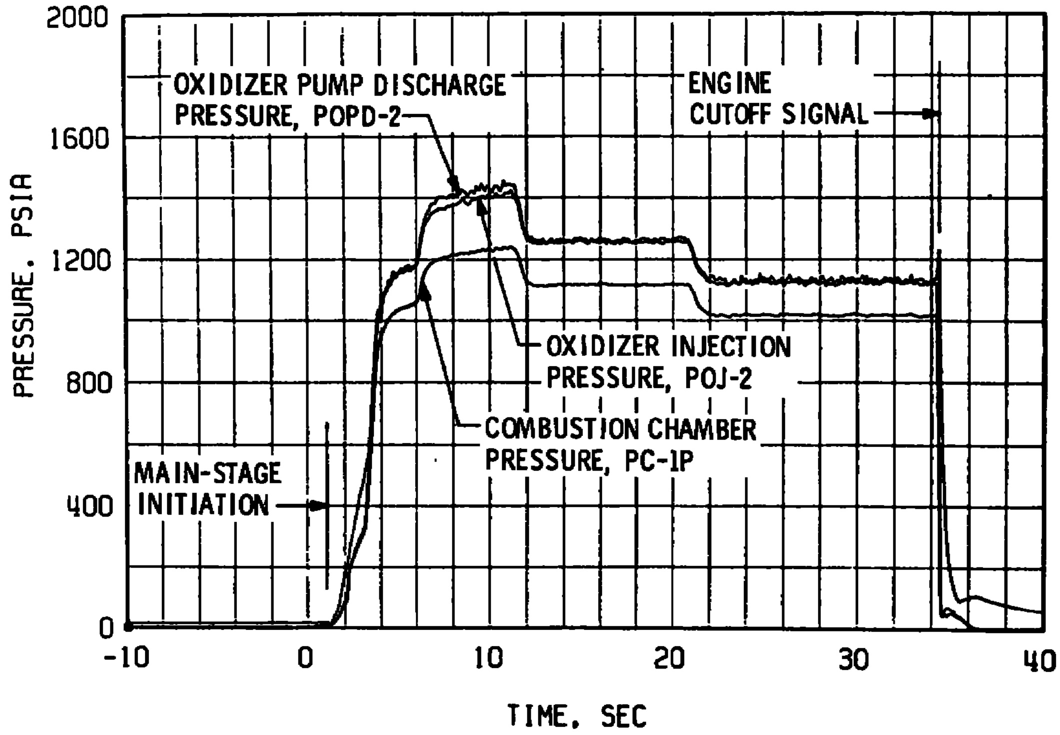


Fig. 12 Solid-Propellant Turbine Starter Chamber Pressure, Firing 04A



a. Fuel



b. Oxidizer

Fig. 13 Propellant Feed System Performance, Firing 04A

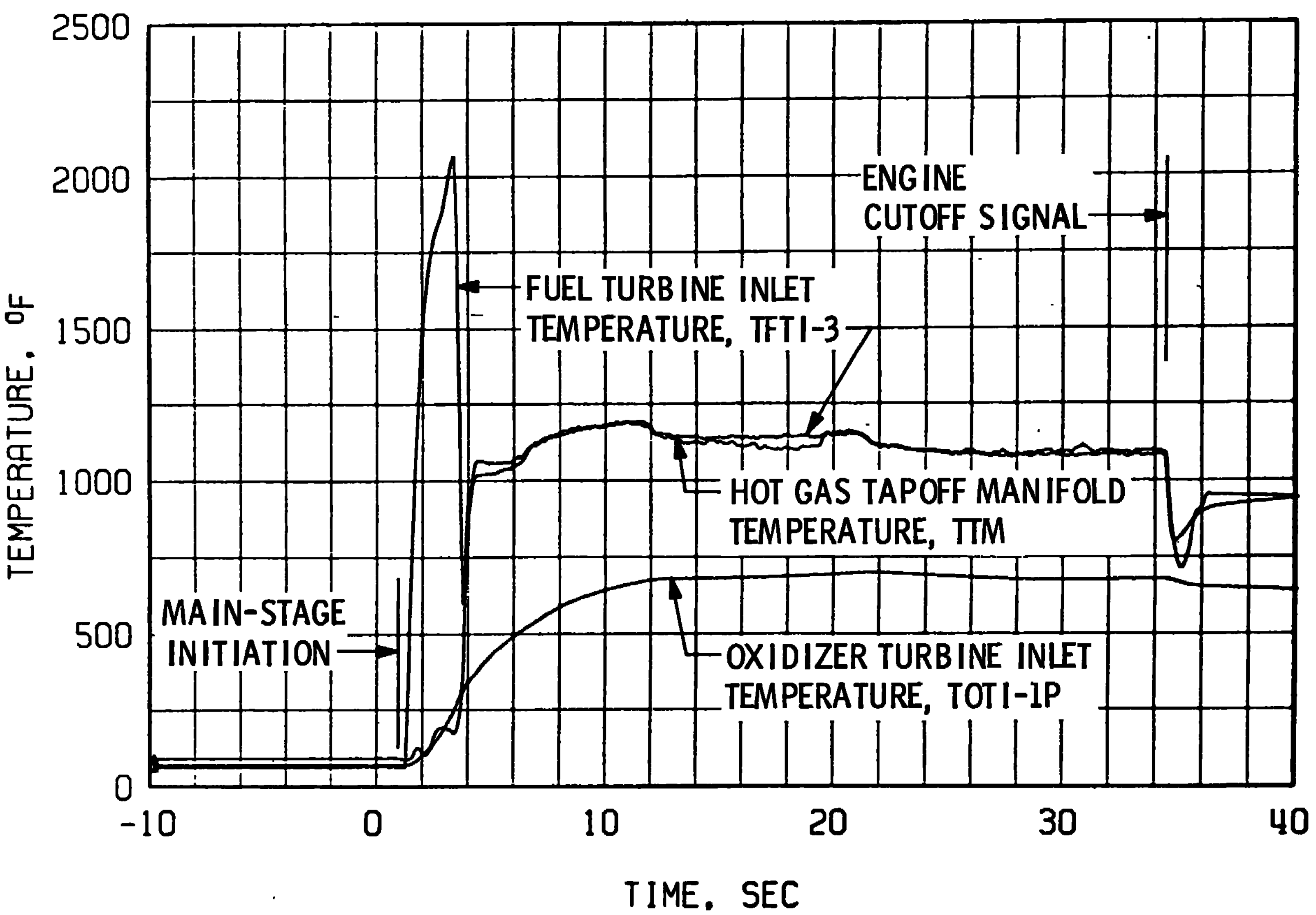


Fig. 14 Turbine System Temperatures, Firing 04A

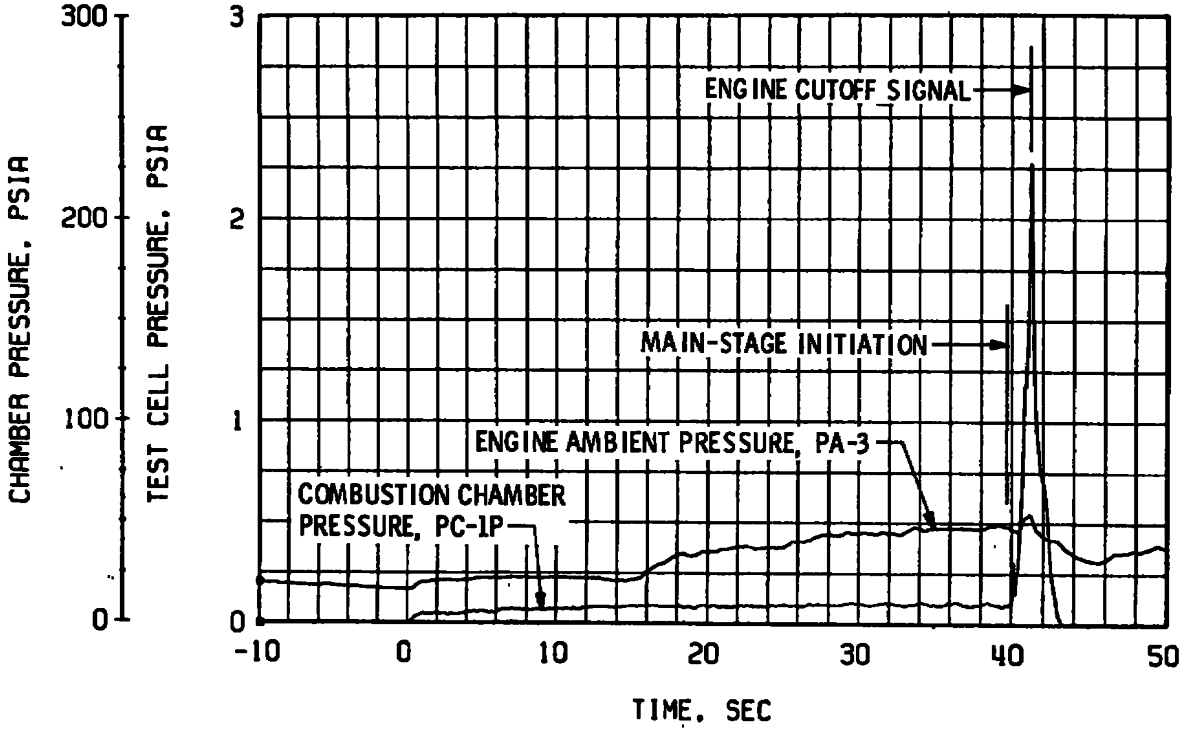


Fig. 15 Engine Ambient and Combustion Chamber Pressures, Firing 04B

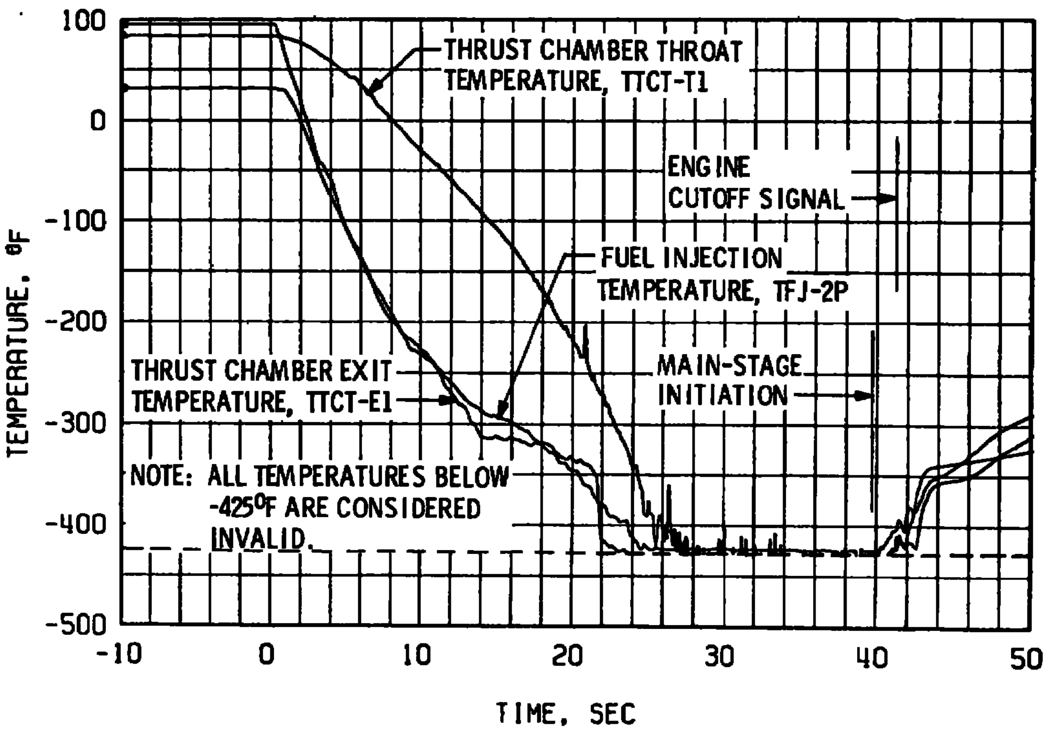


Fig. 16 Thrust Chamber Chilldown and Fuel Injection Temperature, Firing 04B

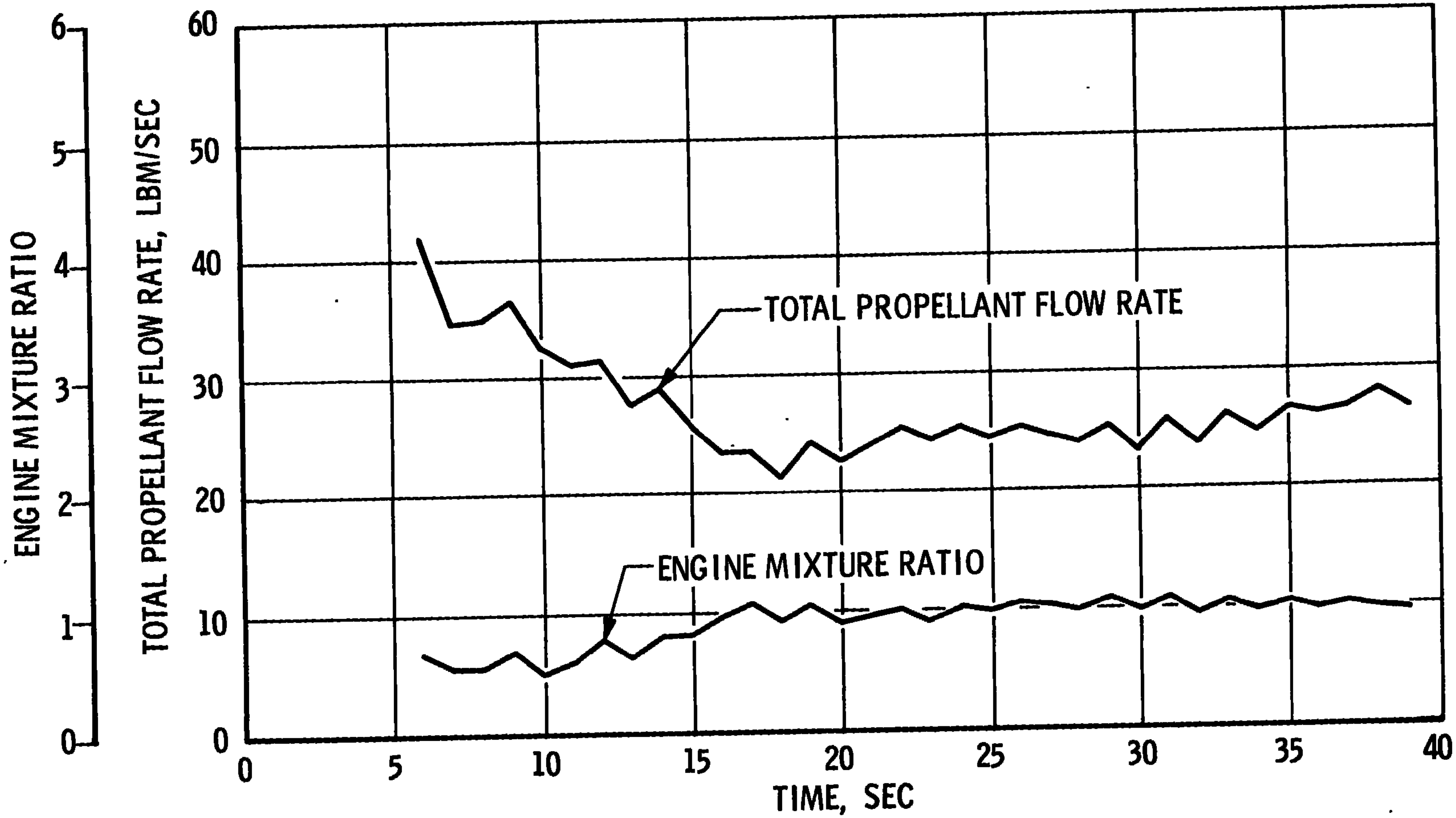


Fig. 17 Total Propellant Flow Rate and Engine Mixture Ratio, Firing 04B

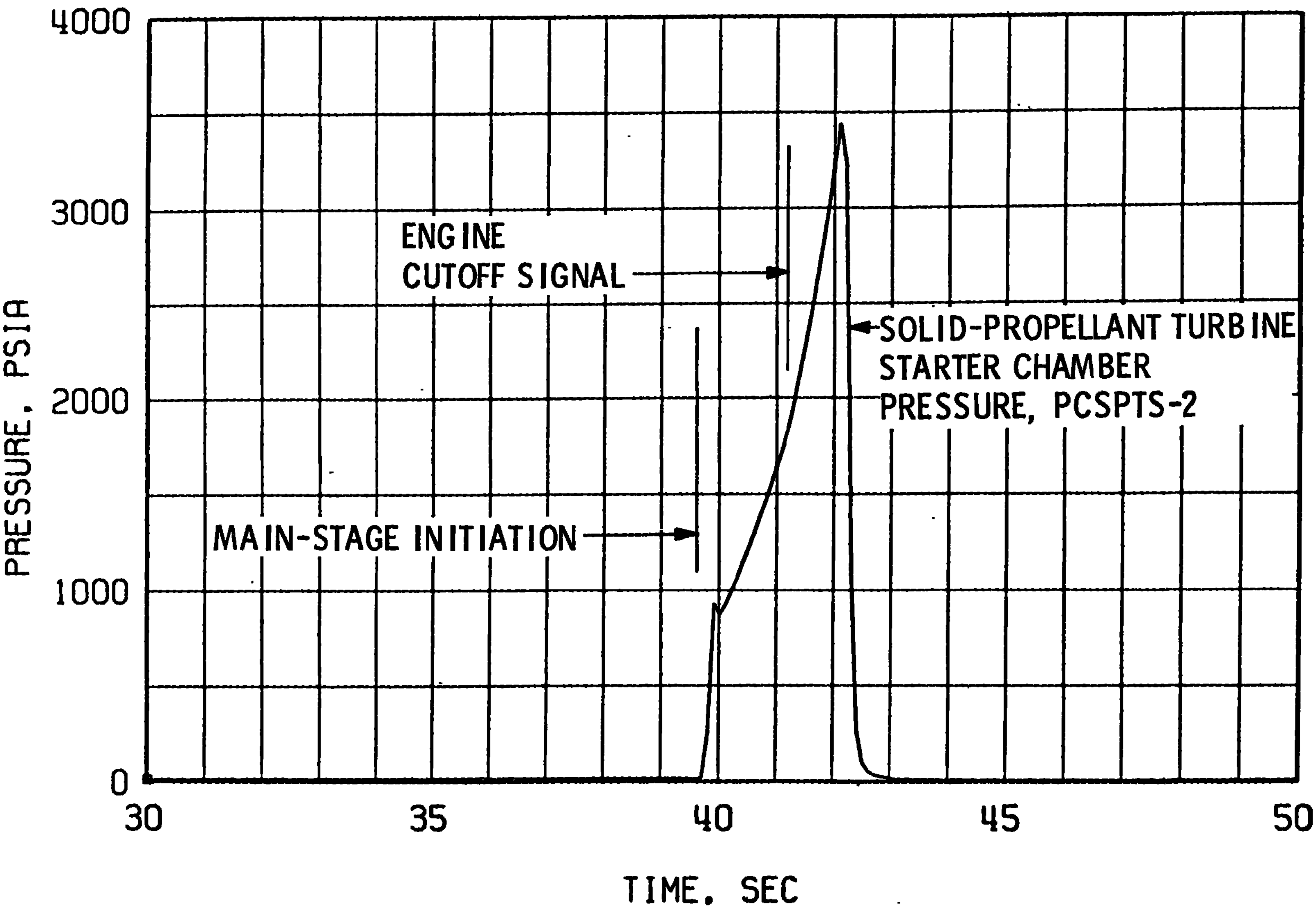
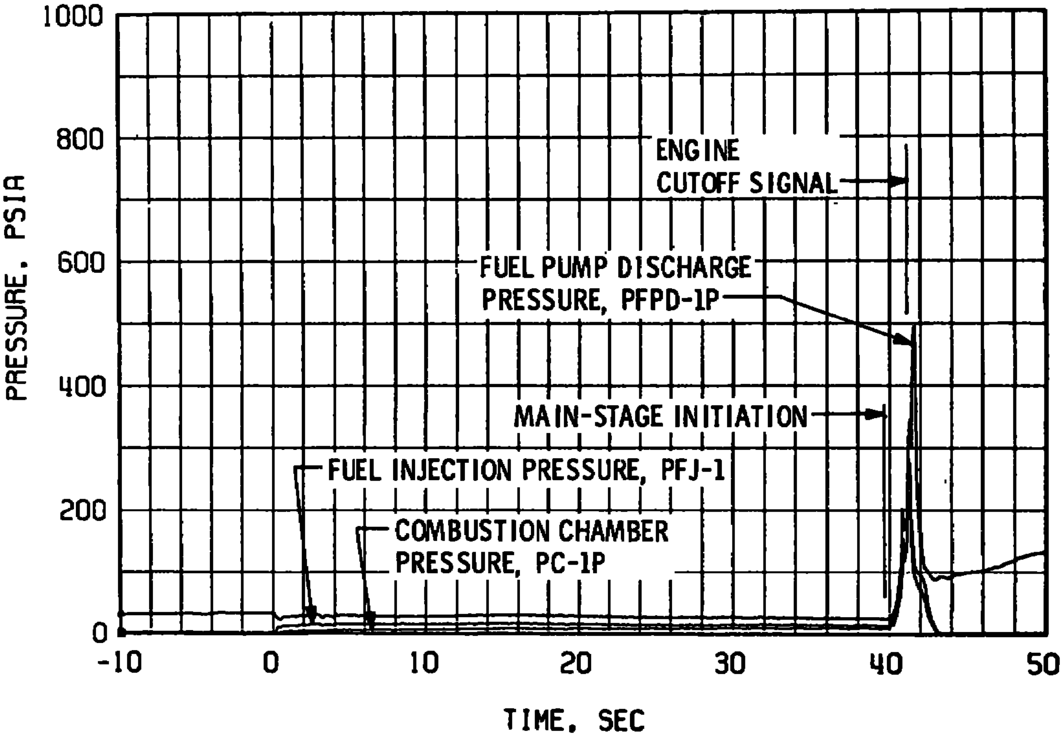
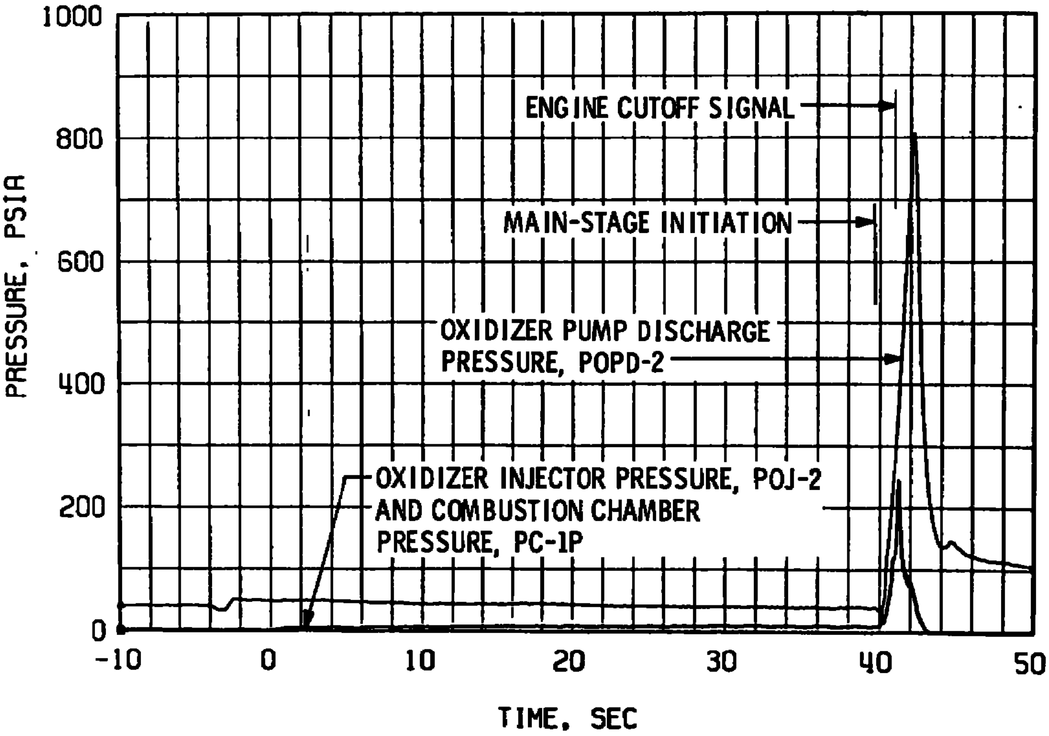


Fig. 18 Solid-Propellant Turbine Starter Chamber Pressure, Firing 04B



a. Fuel



b. Oxidizer

Fig. 19 Propellant Feed System Performance, Firing 04B

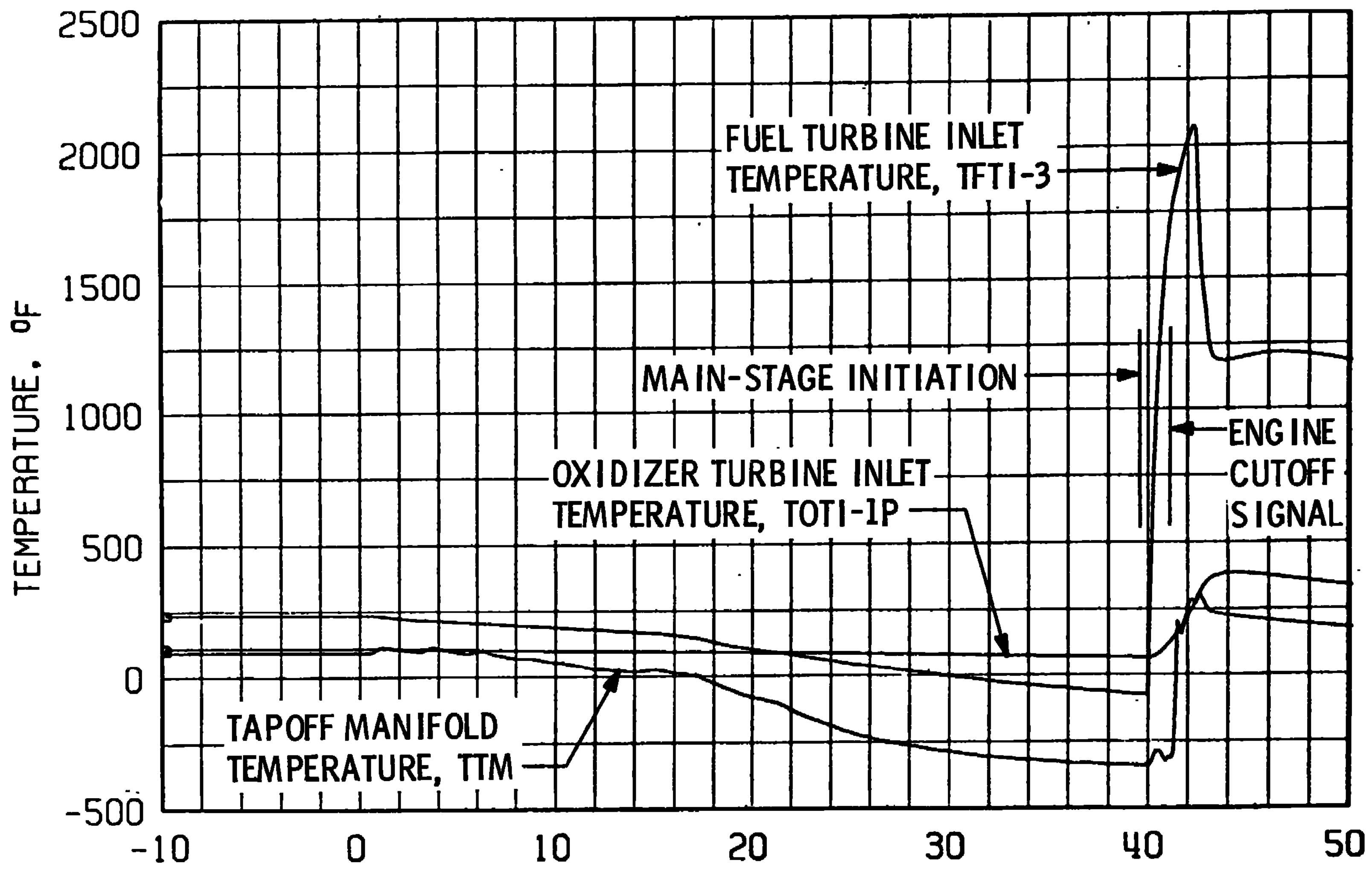


Fig. 20 Turbine System Temperatures, Firing 04B

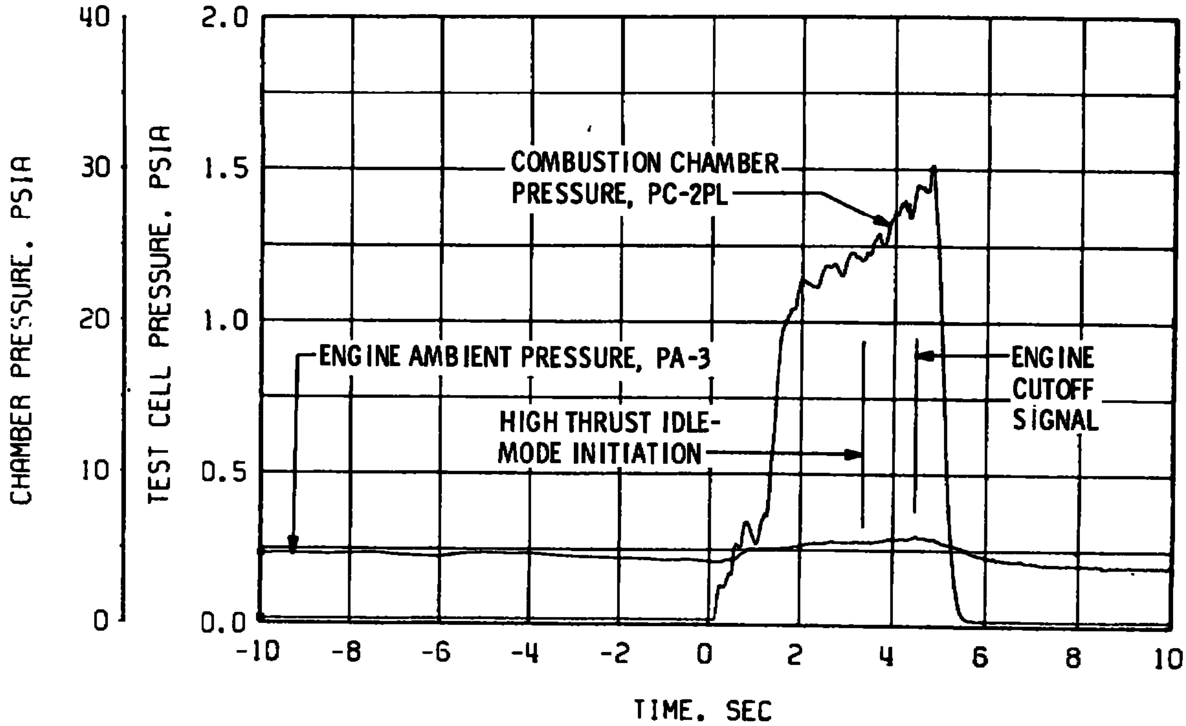


Fig. 21 Engine Ambient and Combustion Chamber Pressures, Firing 05A

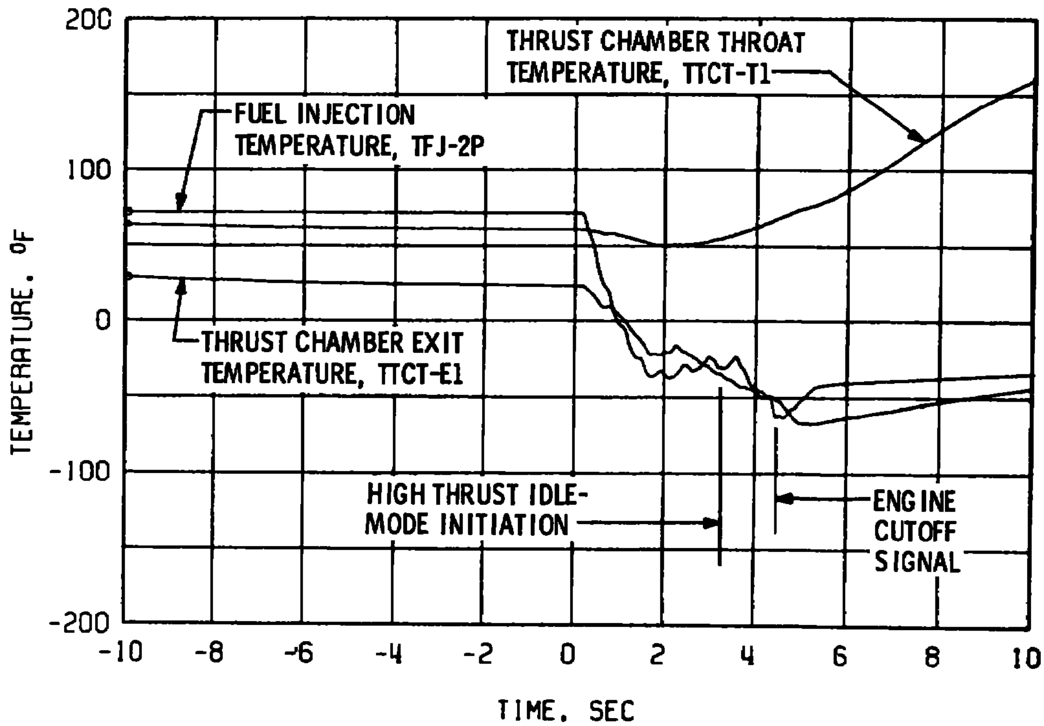
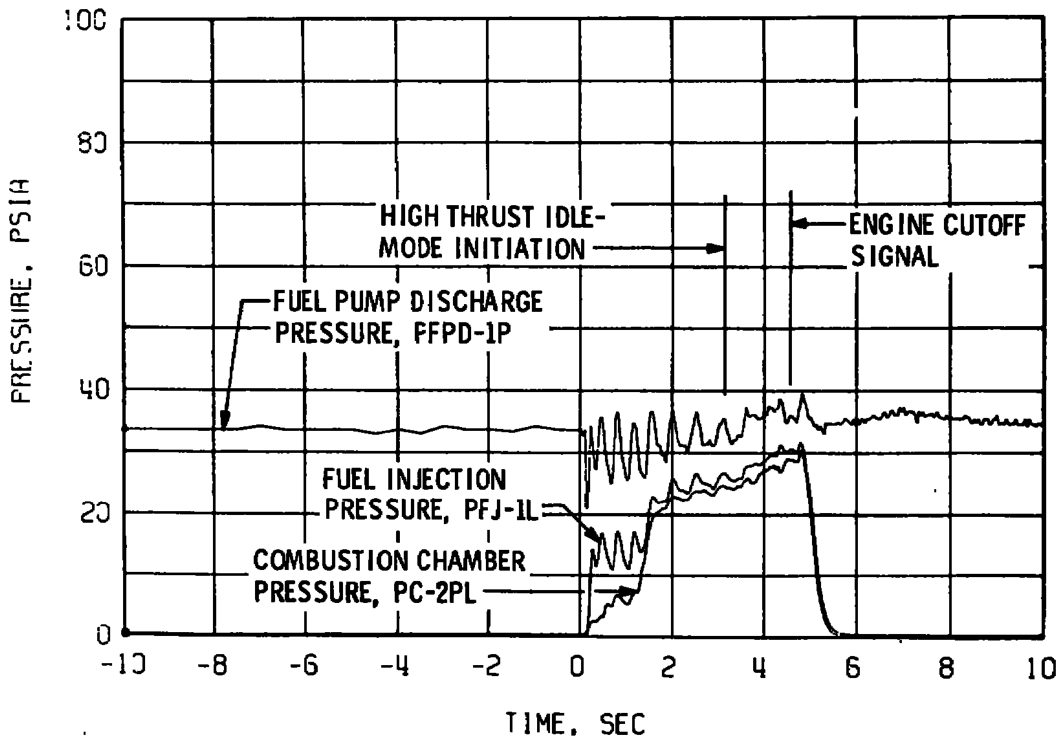
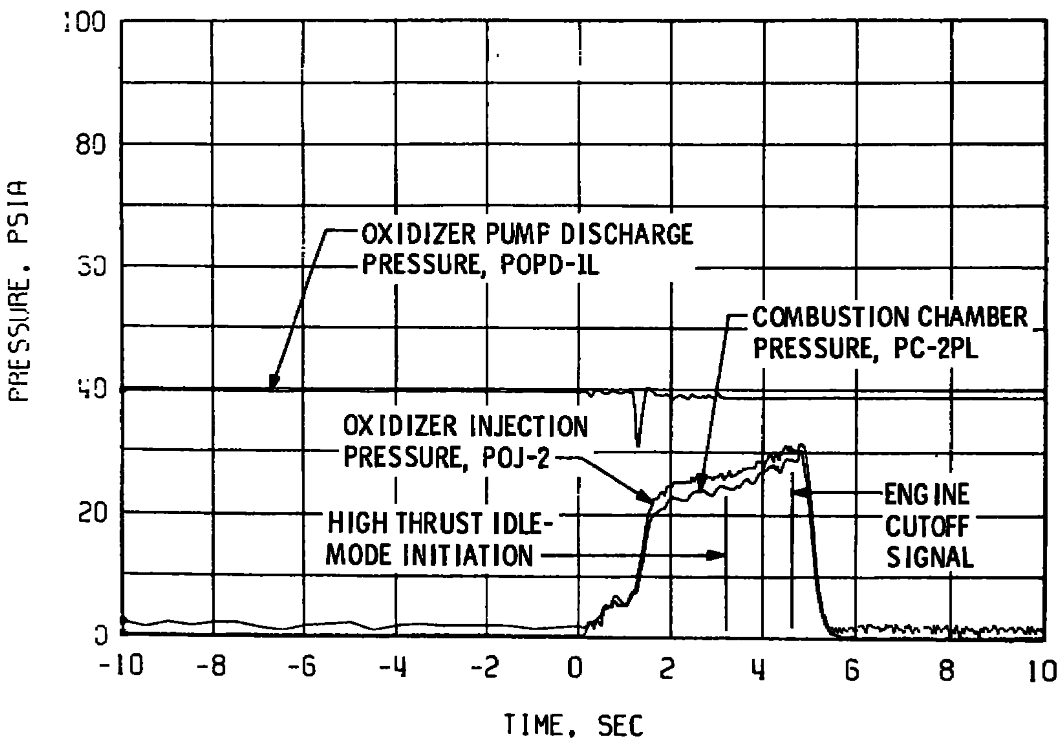


Fig. 22 Thrust Chamber Chilldown and Fuel Injection Temperature, Firing 05A



a. Fuel



b. Oxidizer

Fig. 23 Propellant Feed System Performance, Firing 05A

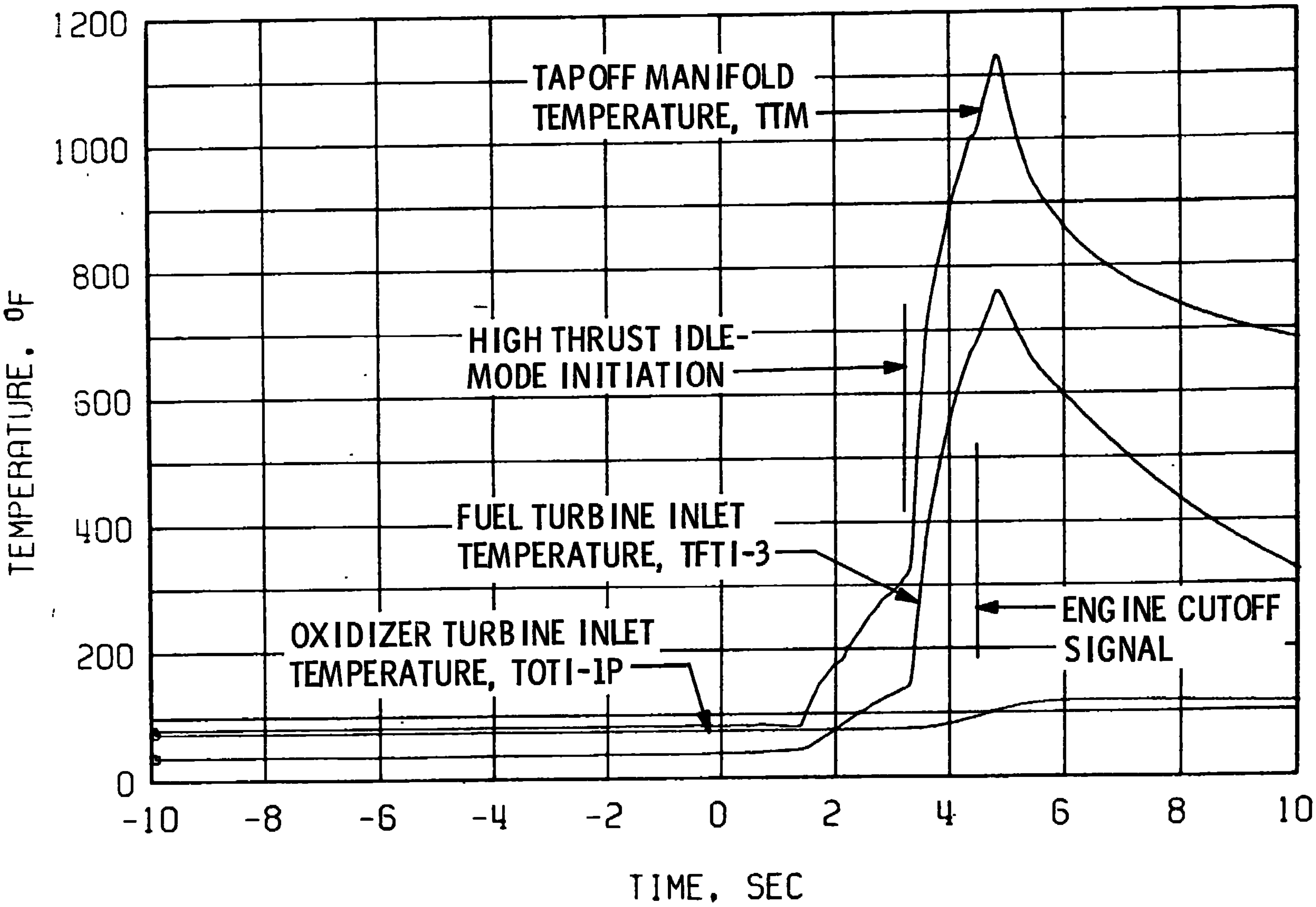


Fig. 24 Turbine System Temperatures, Firing 05A

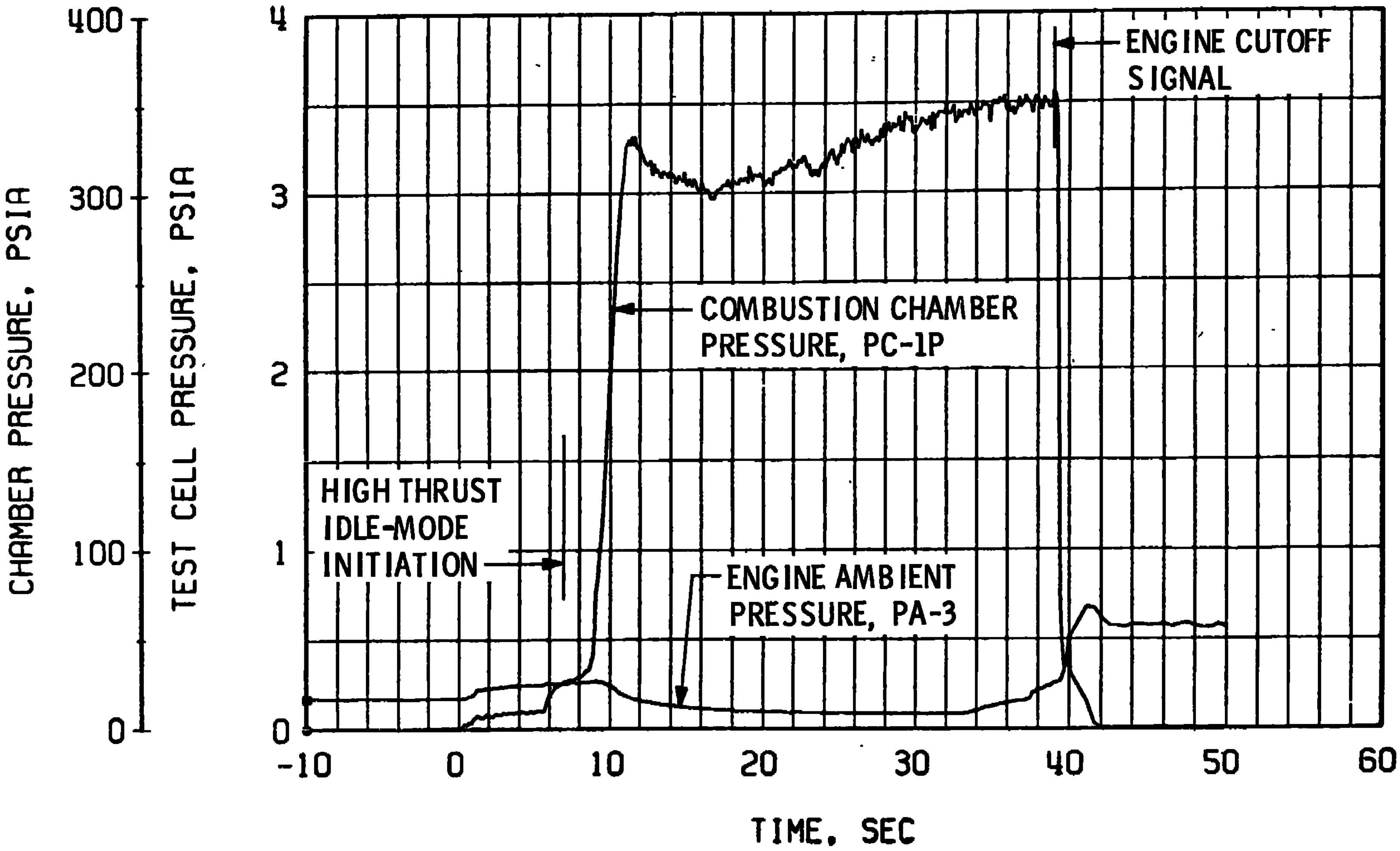


Fig. 25 Engine Ambient and Combustion Chamber Pressures, Firing 05B

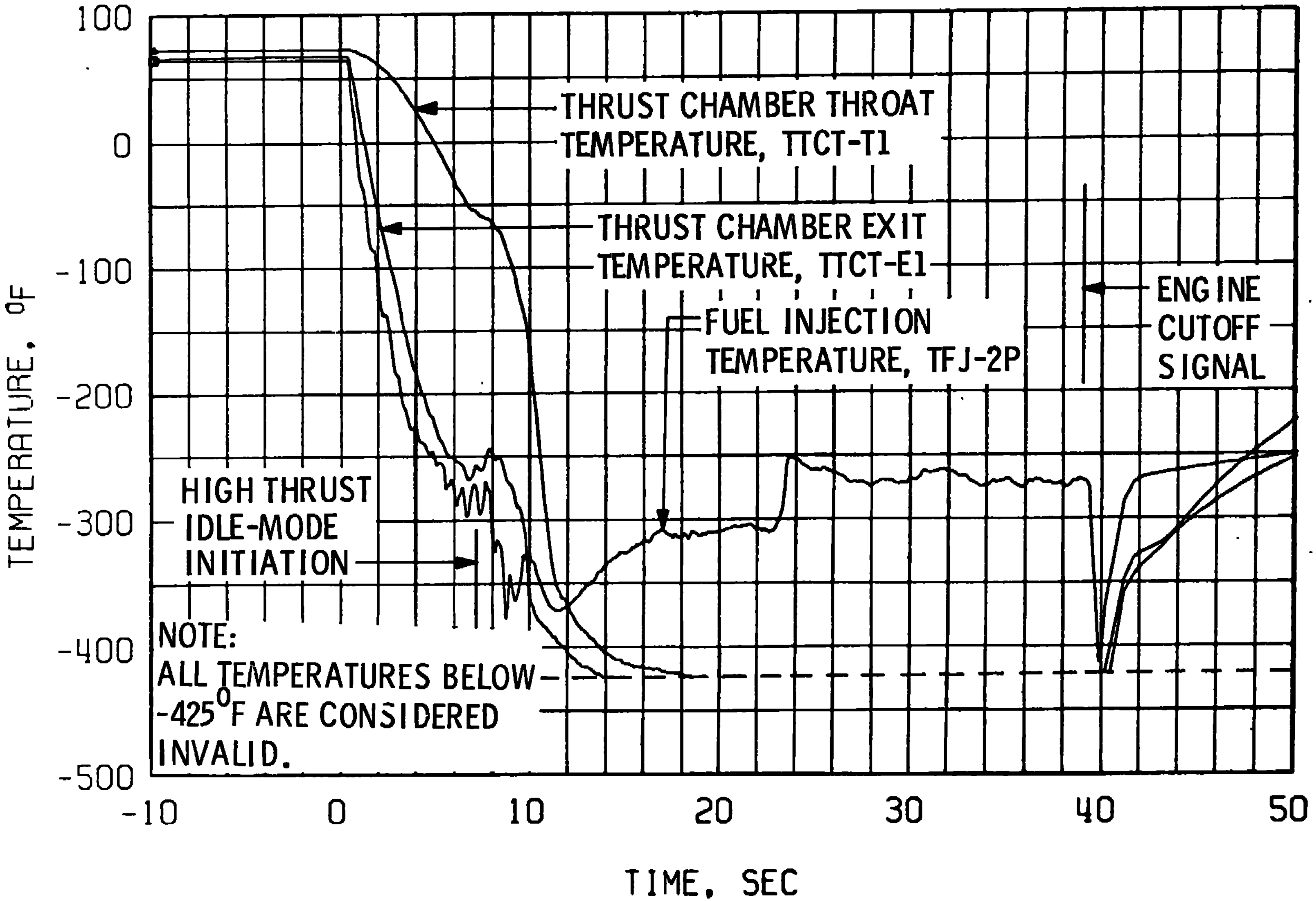


Fig. 26 Thrust Chamber Chilldown and Fuel Injection Temperature, Firing 05B

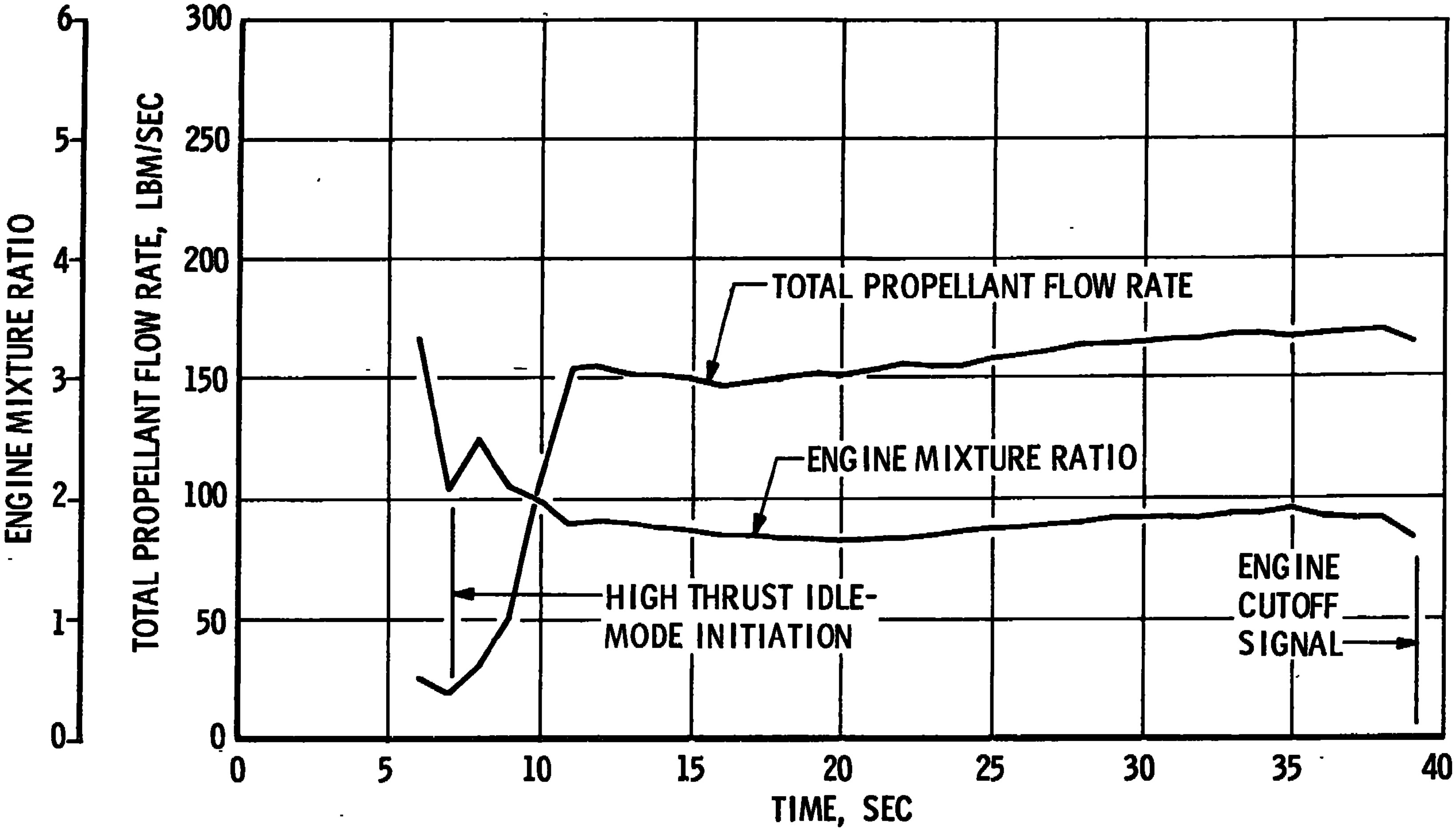
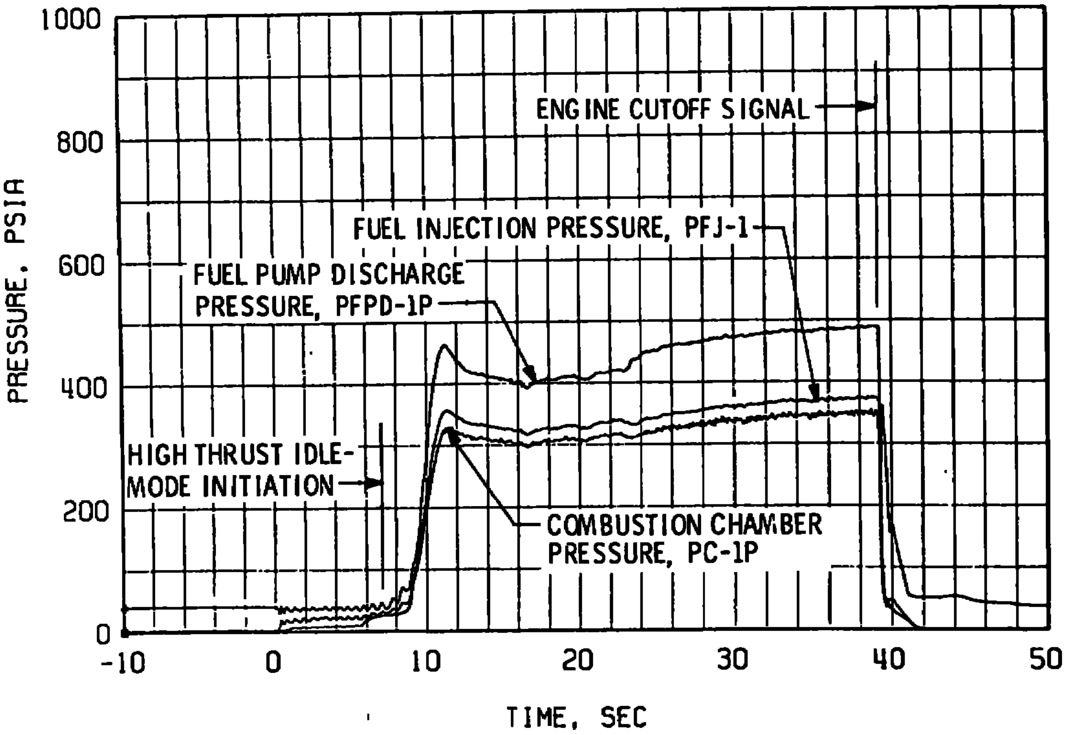
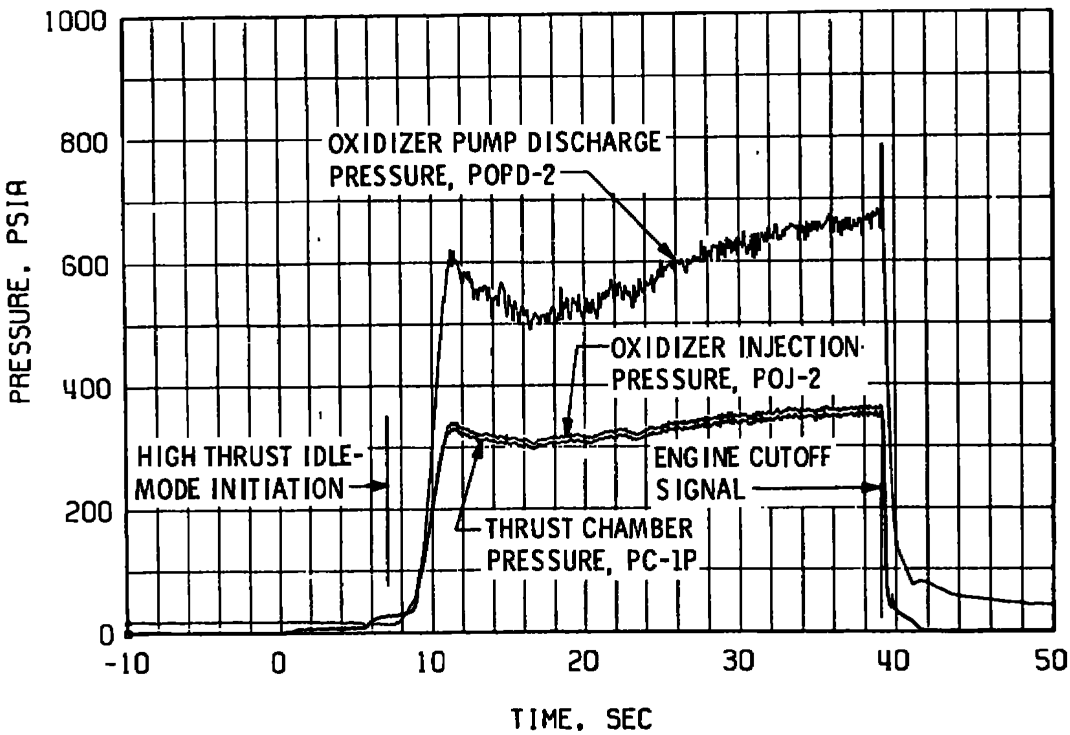


Fig. 27 Total Propellant Flow Rate and Engine Mixture Ratio, Firing 05B



a. Fuel



b. Oxidizer

Fig. 28 Propellant Feed System Performance, Firing 05B

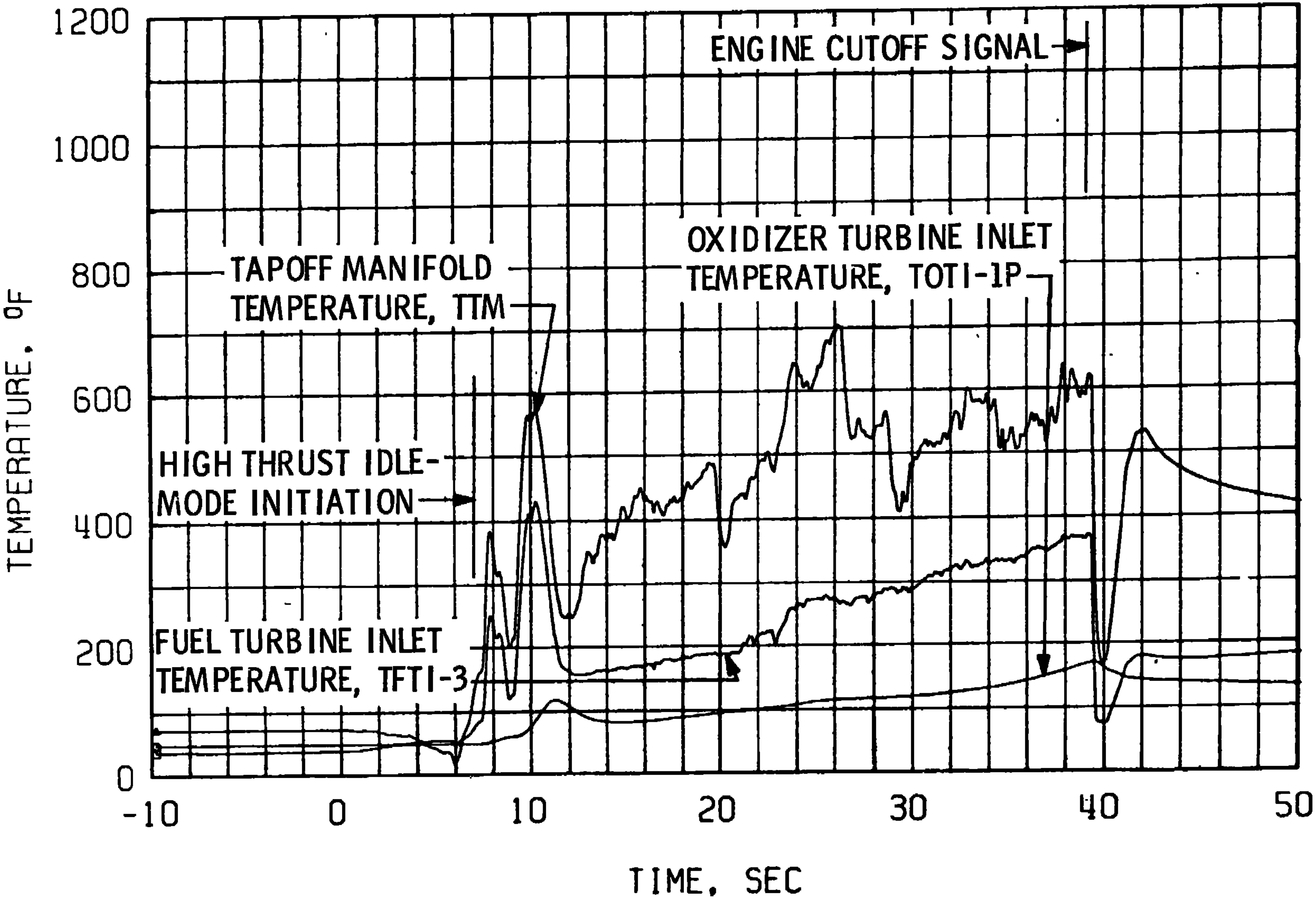


Fig. 29 Turbine System Temperatures, Firing 05B

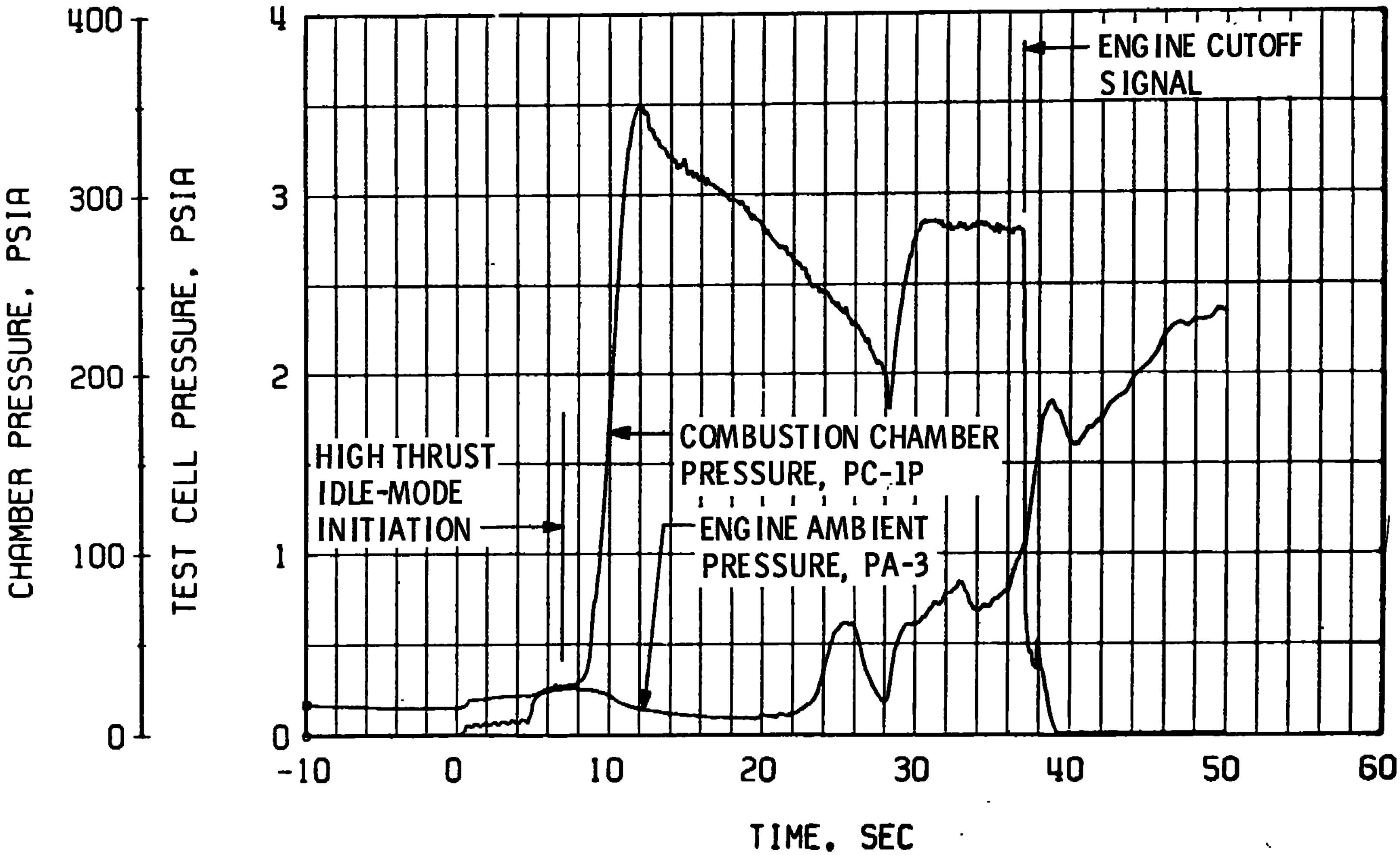


Fig. 30 Engine Ambient and Combustion Chamber Pressures, Firing 05C

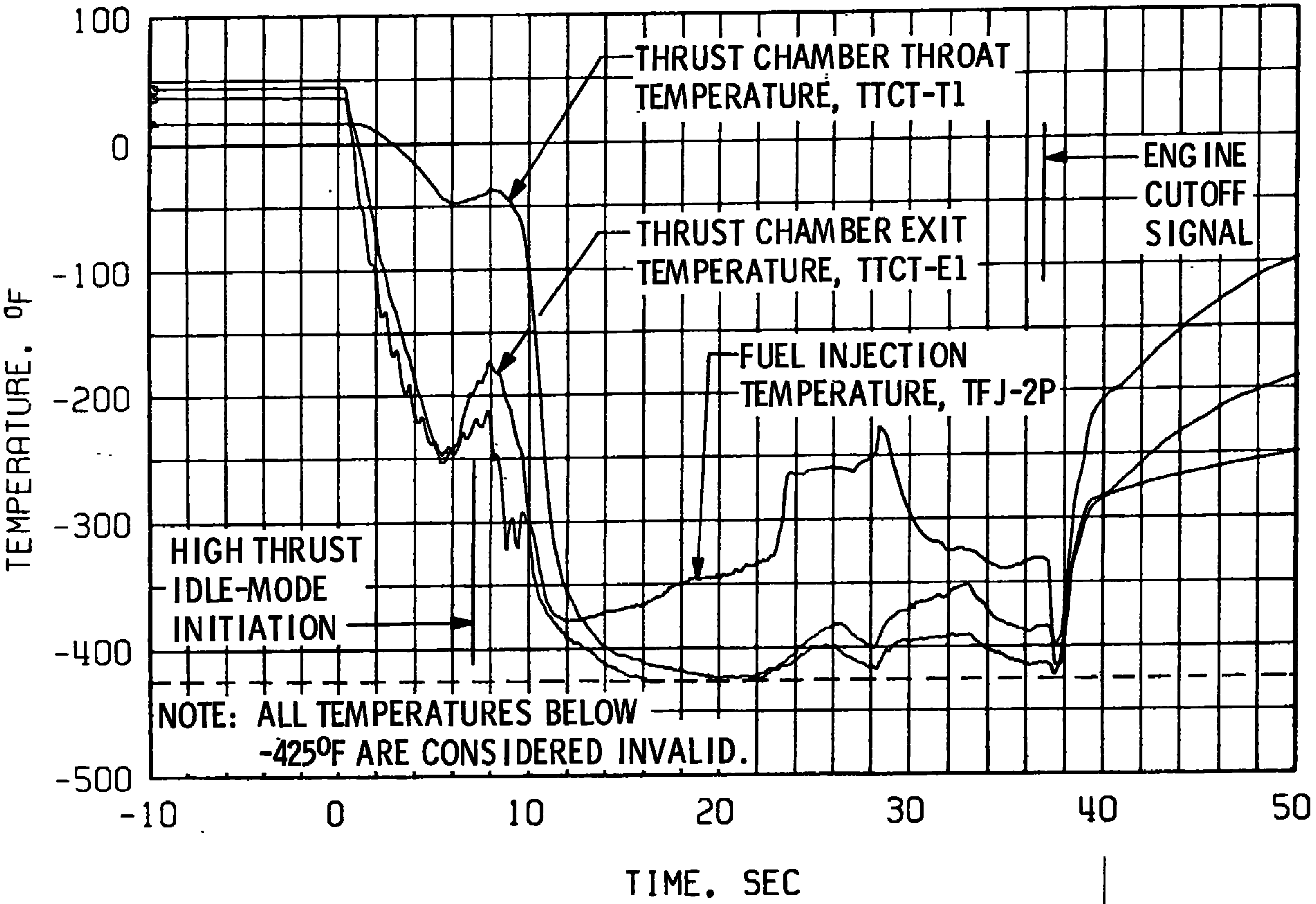


Fig. 31 Thrust Chamber Chilldown and Fuel Injection Temperature, Firing 05C

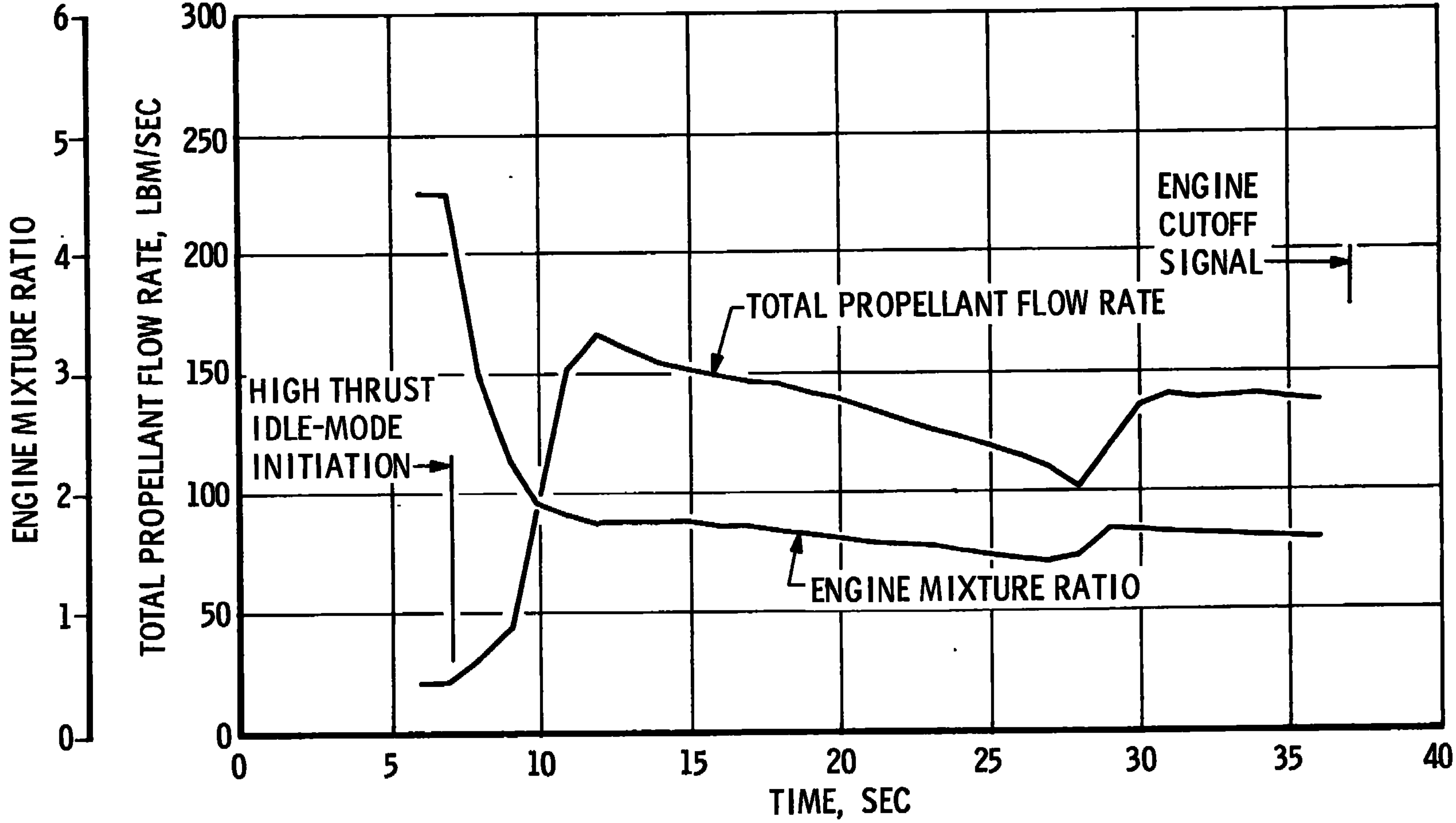
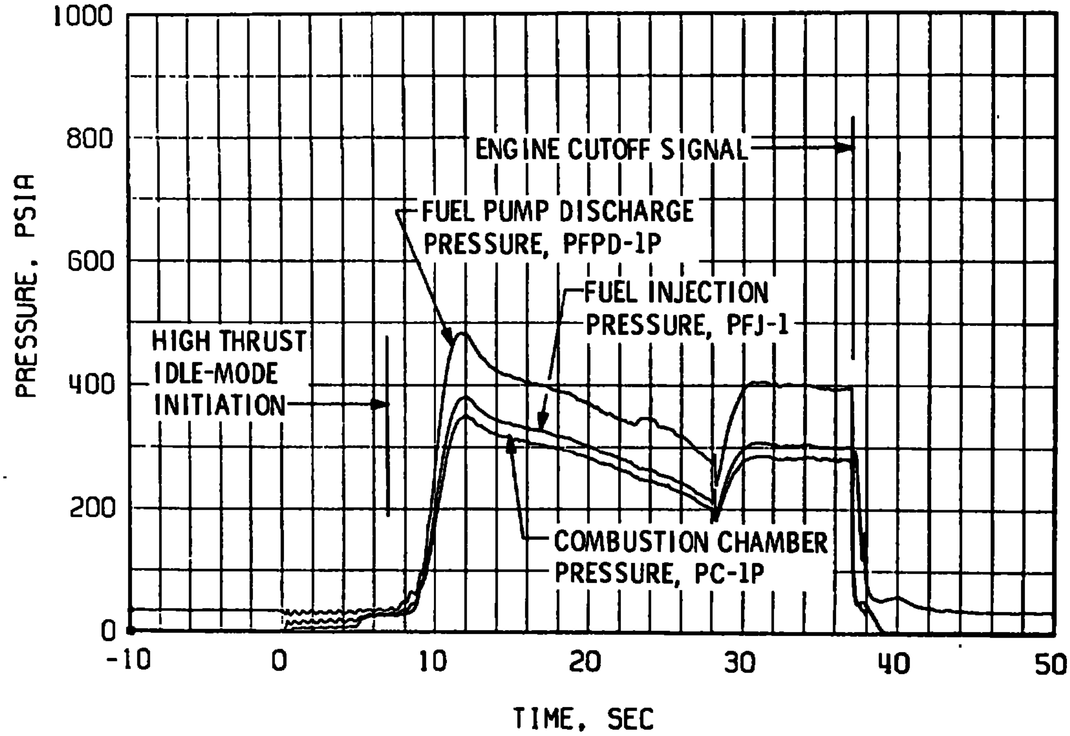
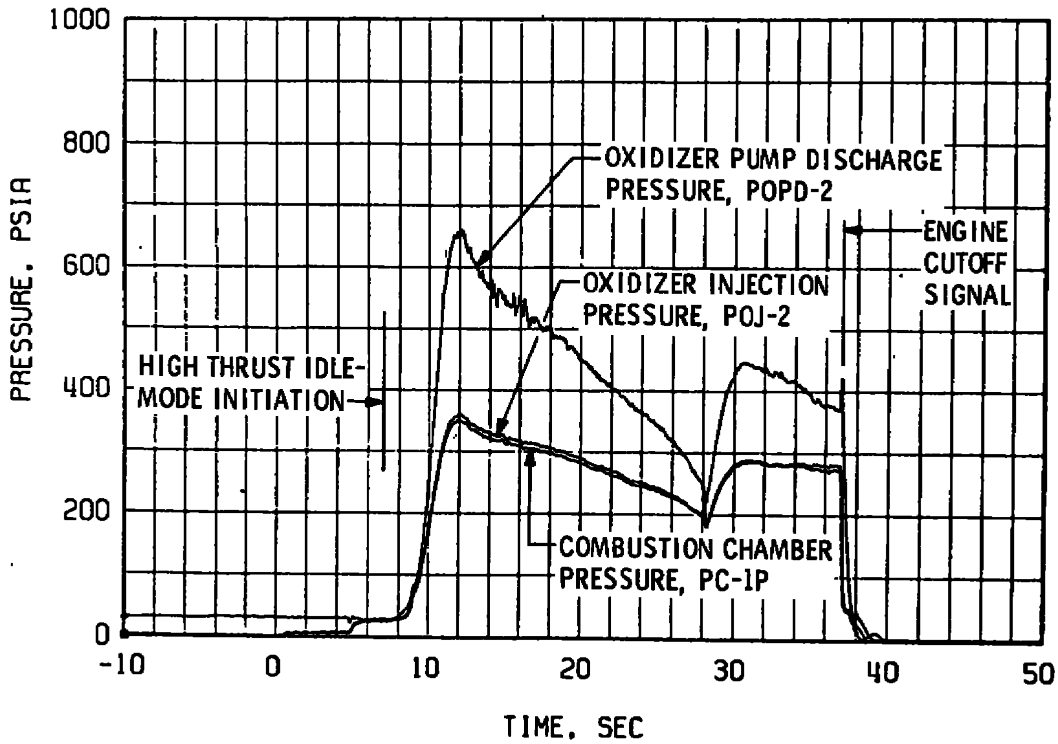


Fig. 32 Total Propellant Flow Rate and Engine Mixture Ratio, Firing 05C



a. Fuel



b. Oxidizer

Fig. 33 Propellant Feed System Performance, Firing 05C

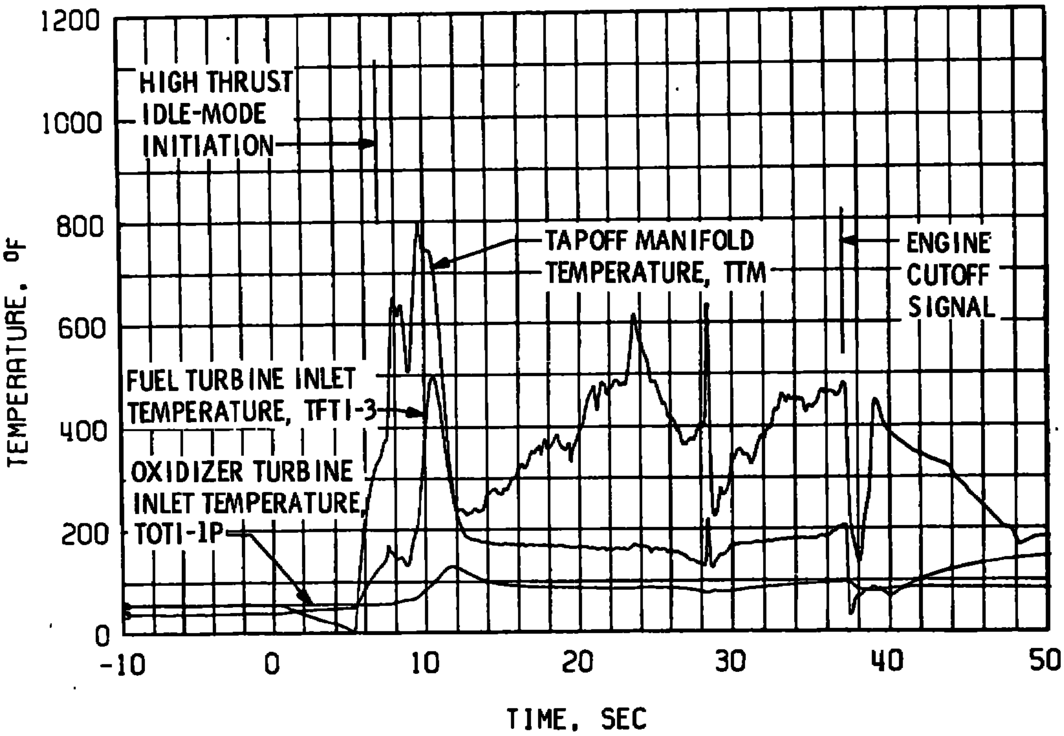


Fig. 34 Turbine System Temperatures, Firing 05C

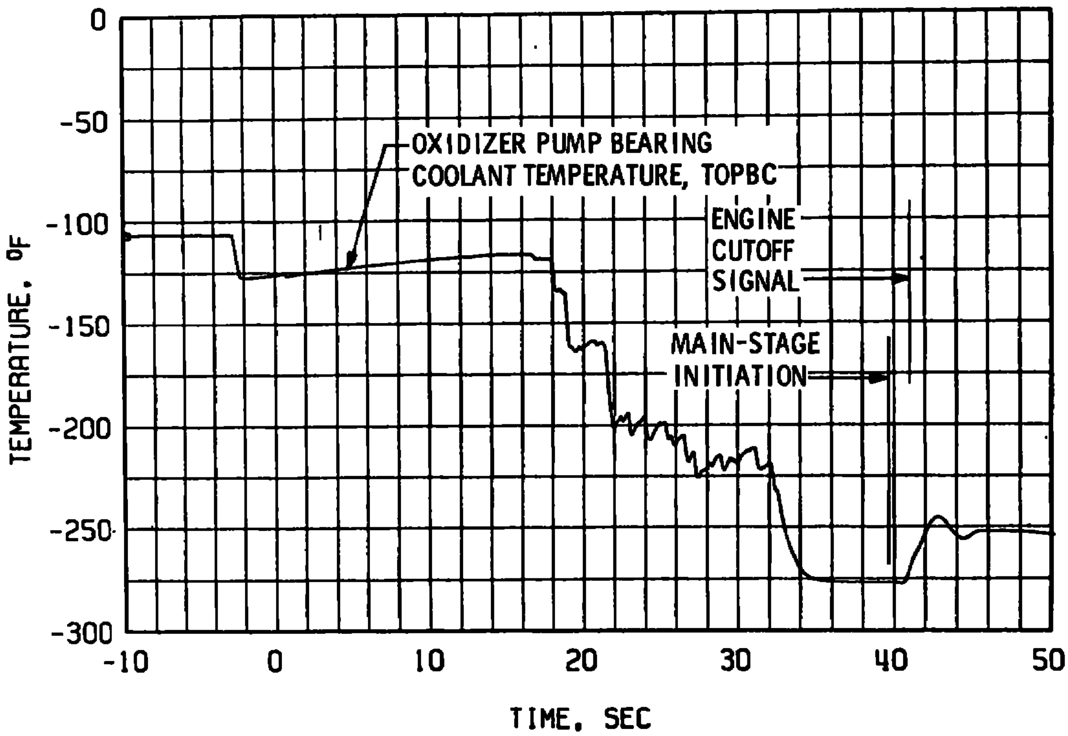
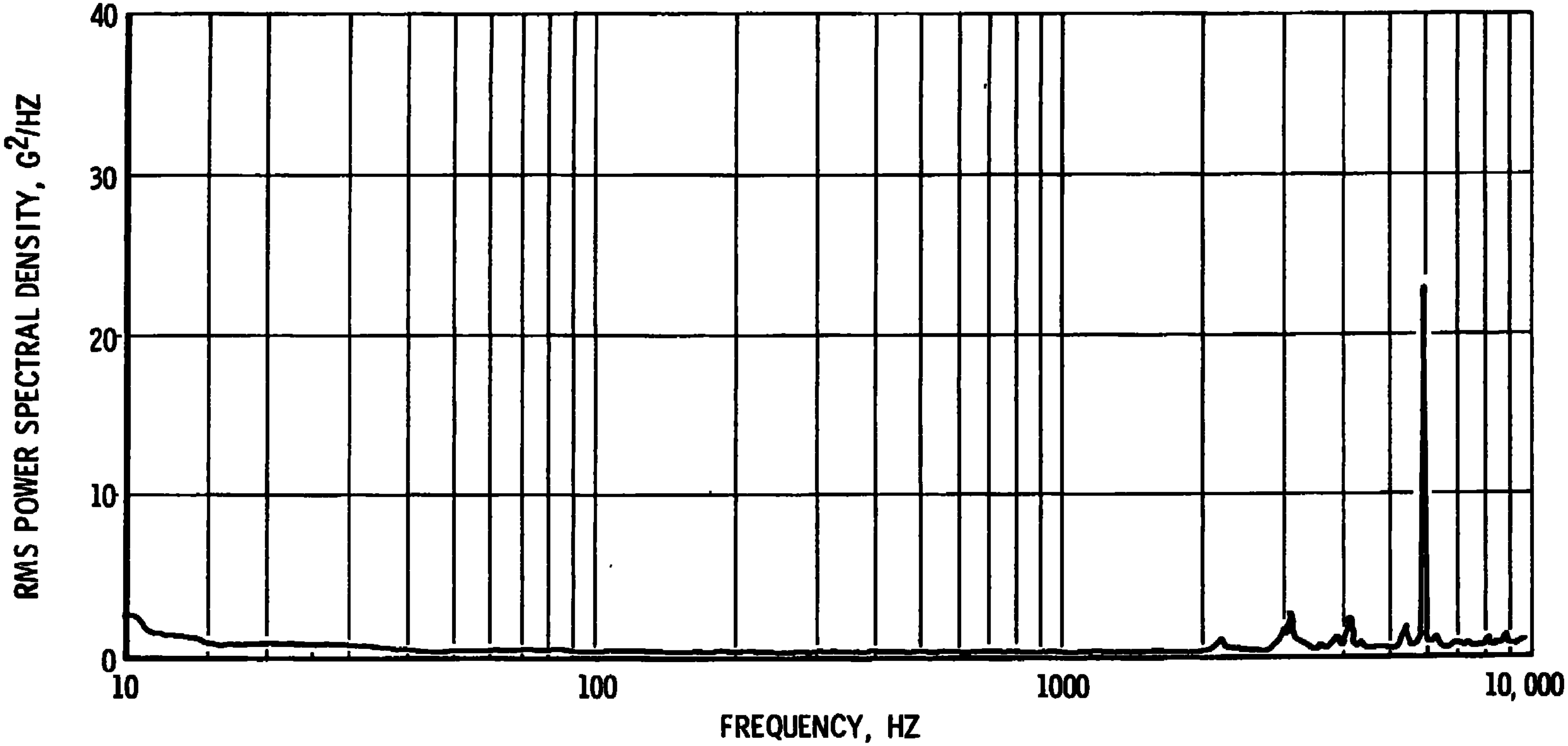
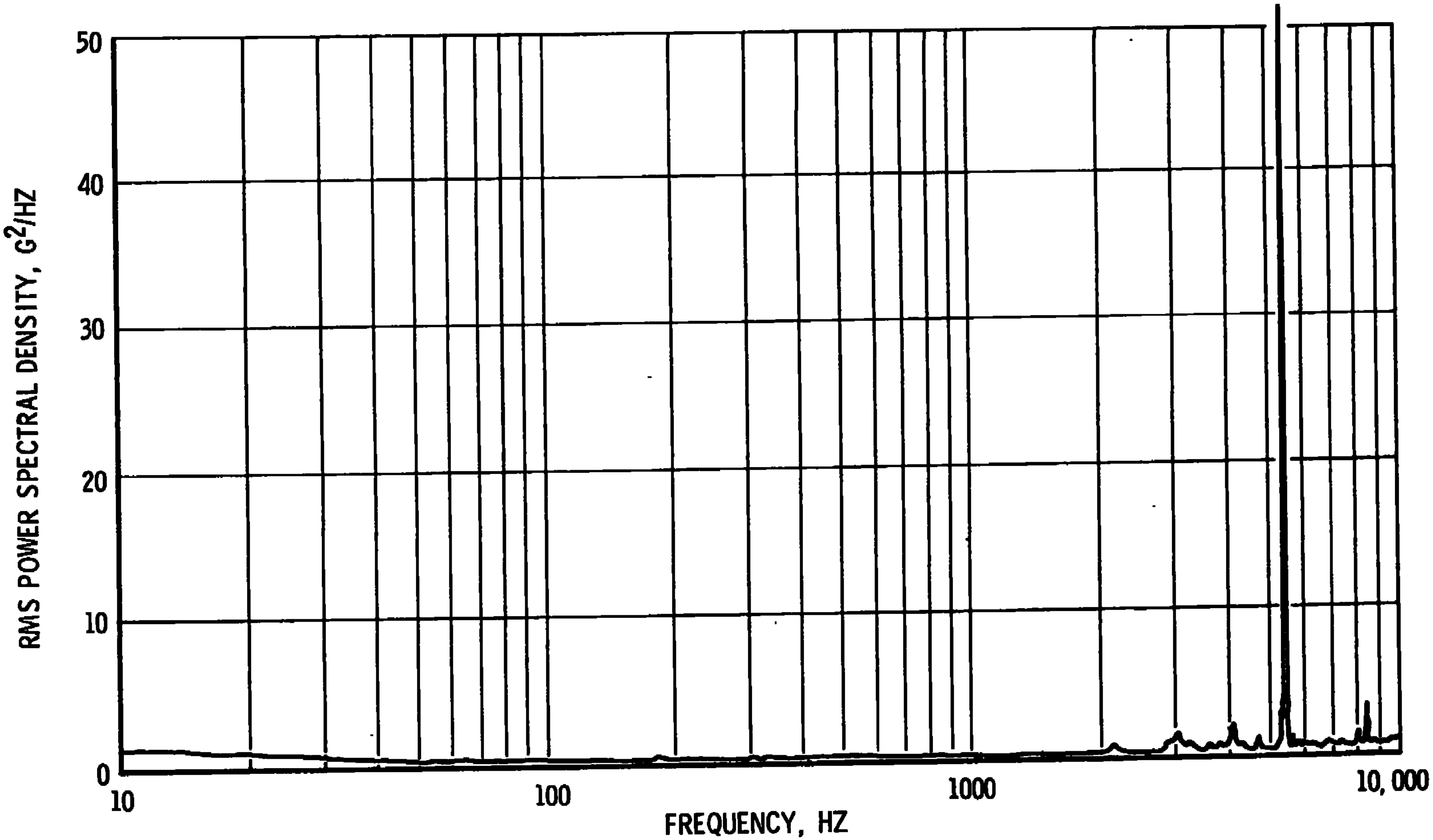


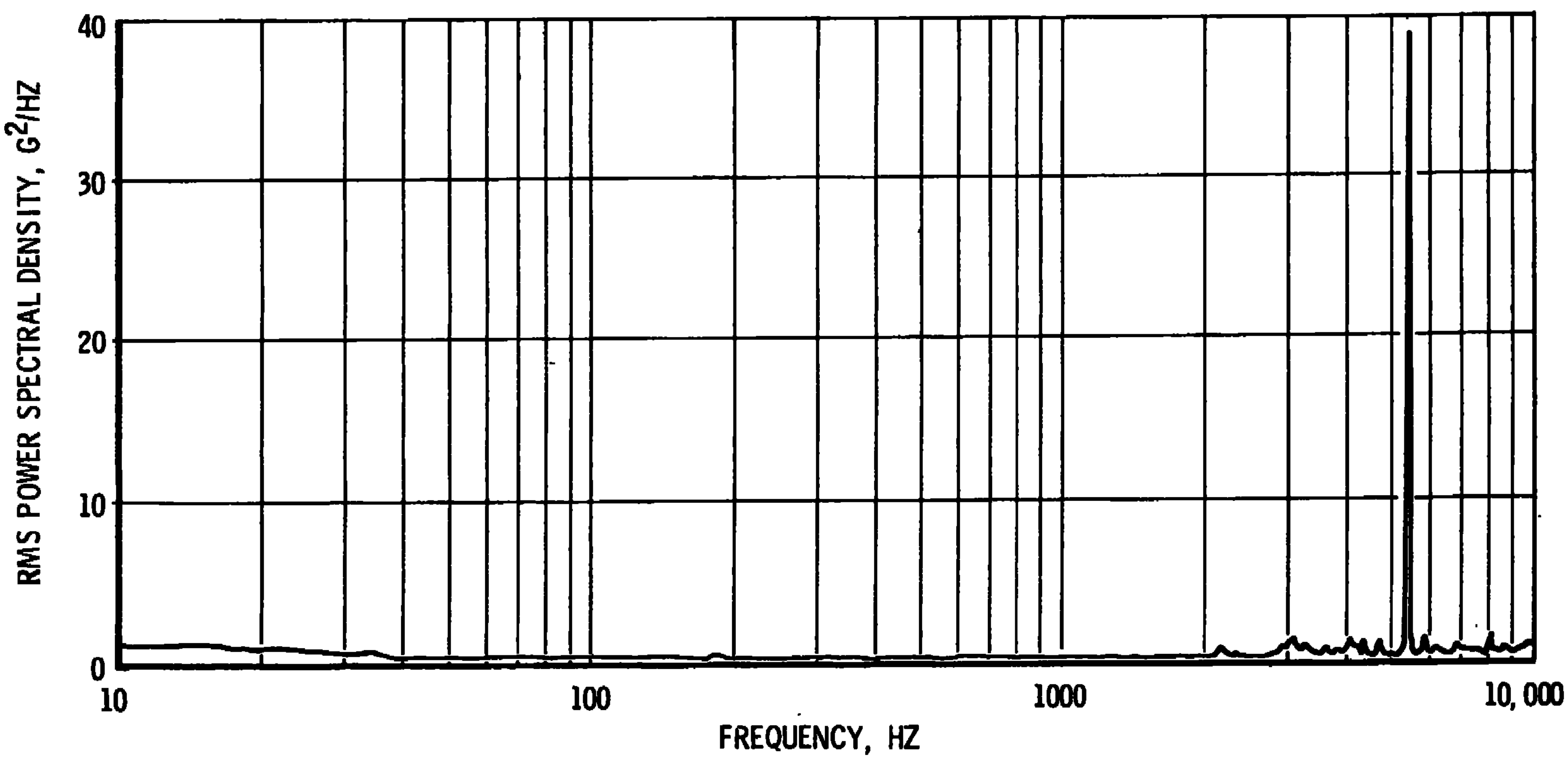
Fig. 35 Oxidizer Pump Bearing Coolant Temperature, Firing 04B



a. Thrust Chamber Dome Accelerometer (UTCD-4) Data with Closed Propellant Utilization Valve
Fig. 36 Power Spectral Density, Firing 04A



b. Thrust Chamber Dome Accelerometer (UTCD-4) Data with Null Propellant Utilization Valve
Fig. 36 Continued



c. Thrust Chamber Dome Accelerometer (UTCD-4) Data with Open Propellant Utilization Valve
Fig. 36 Concluded

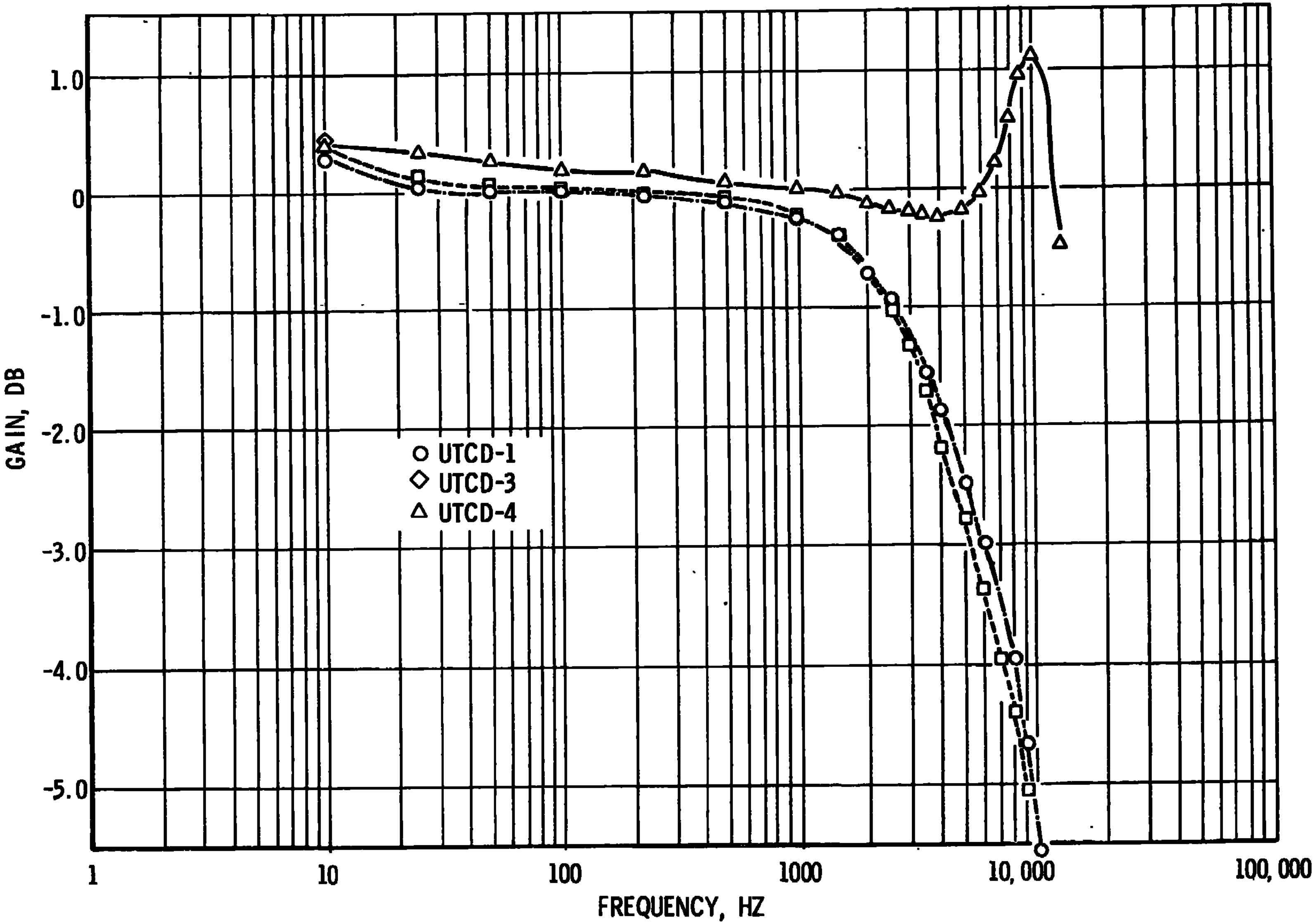


Fig. 37 Accelerometer Output Gain versus Frequency

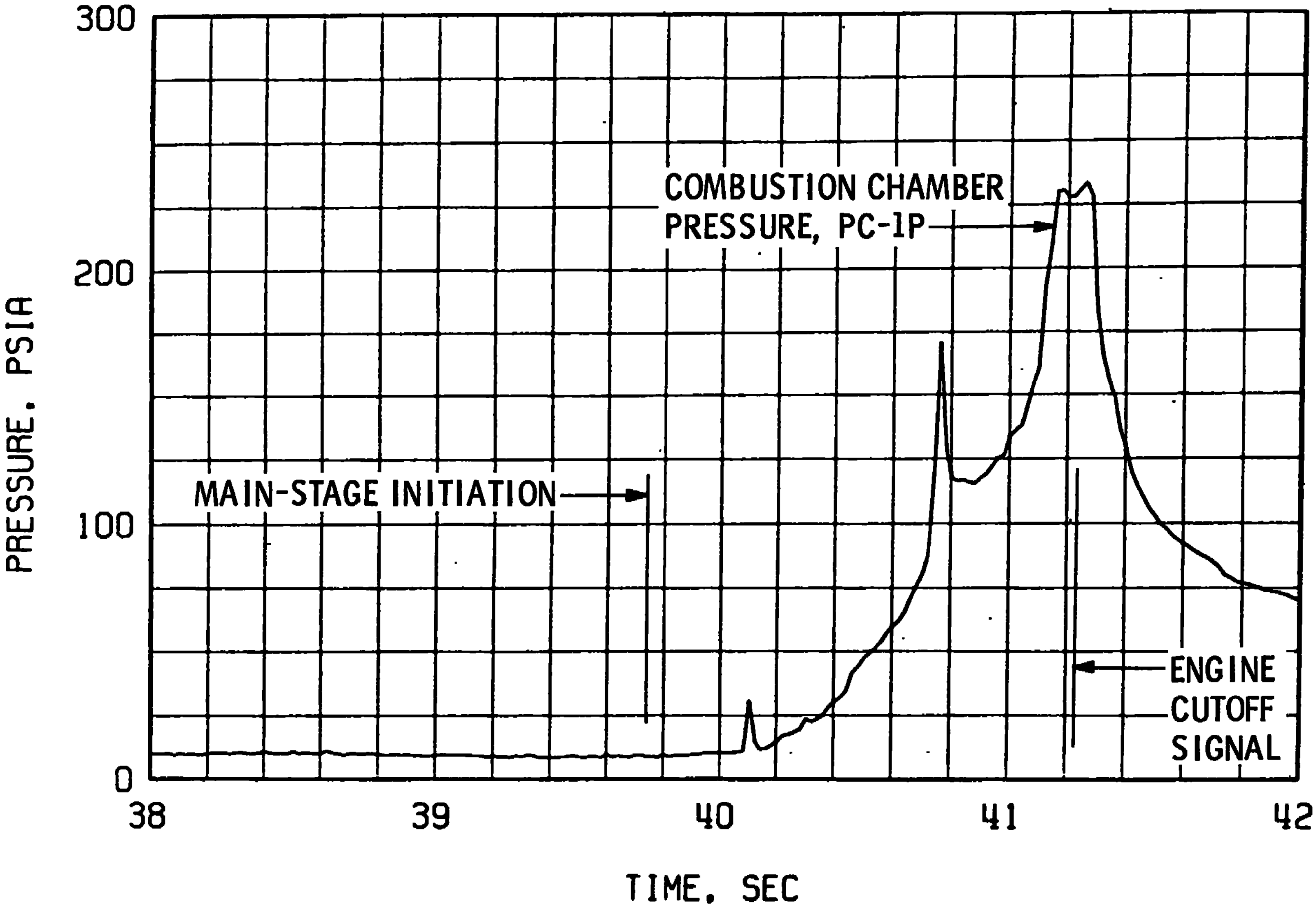
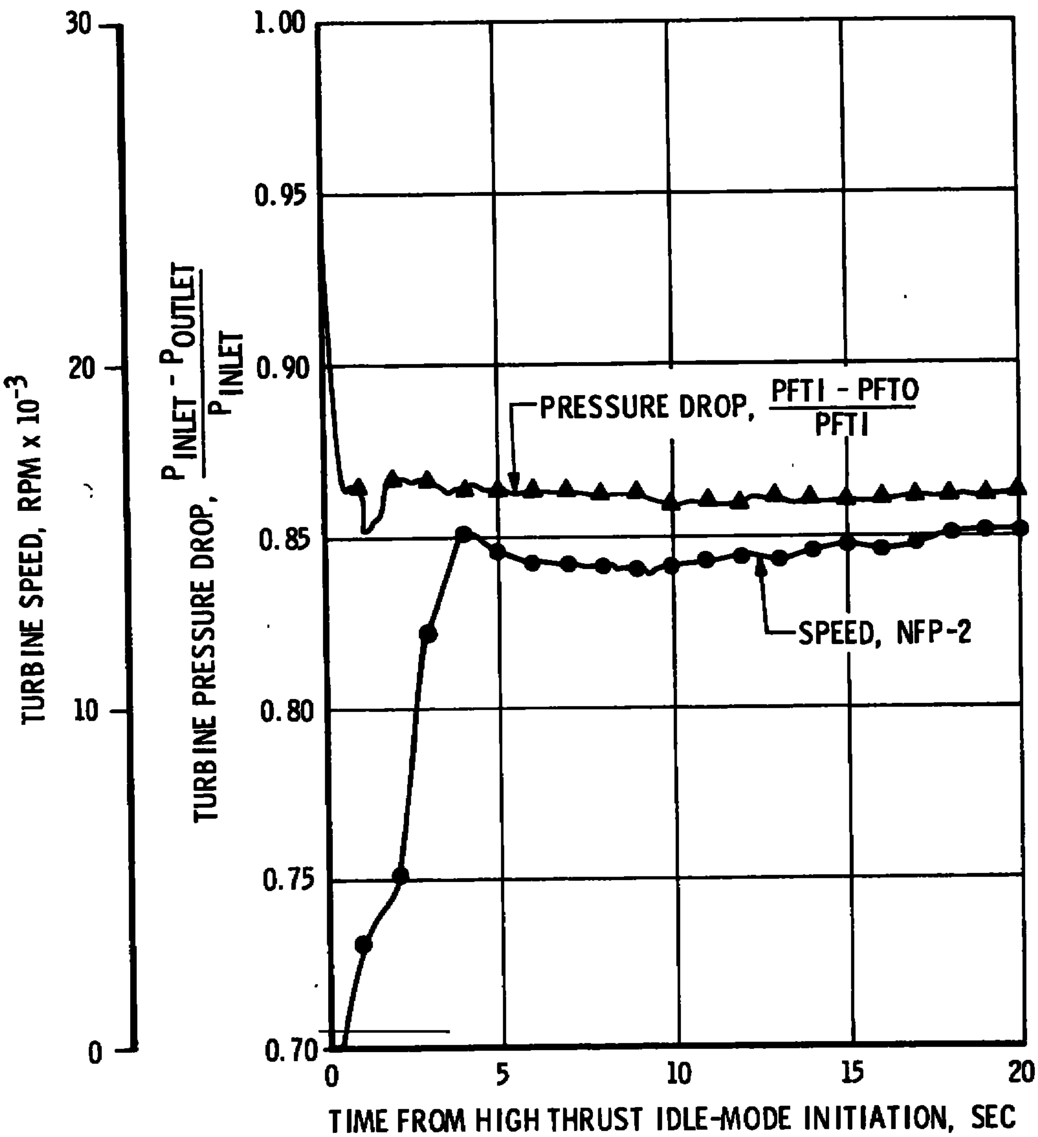
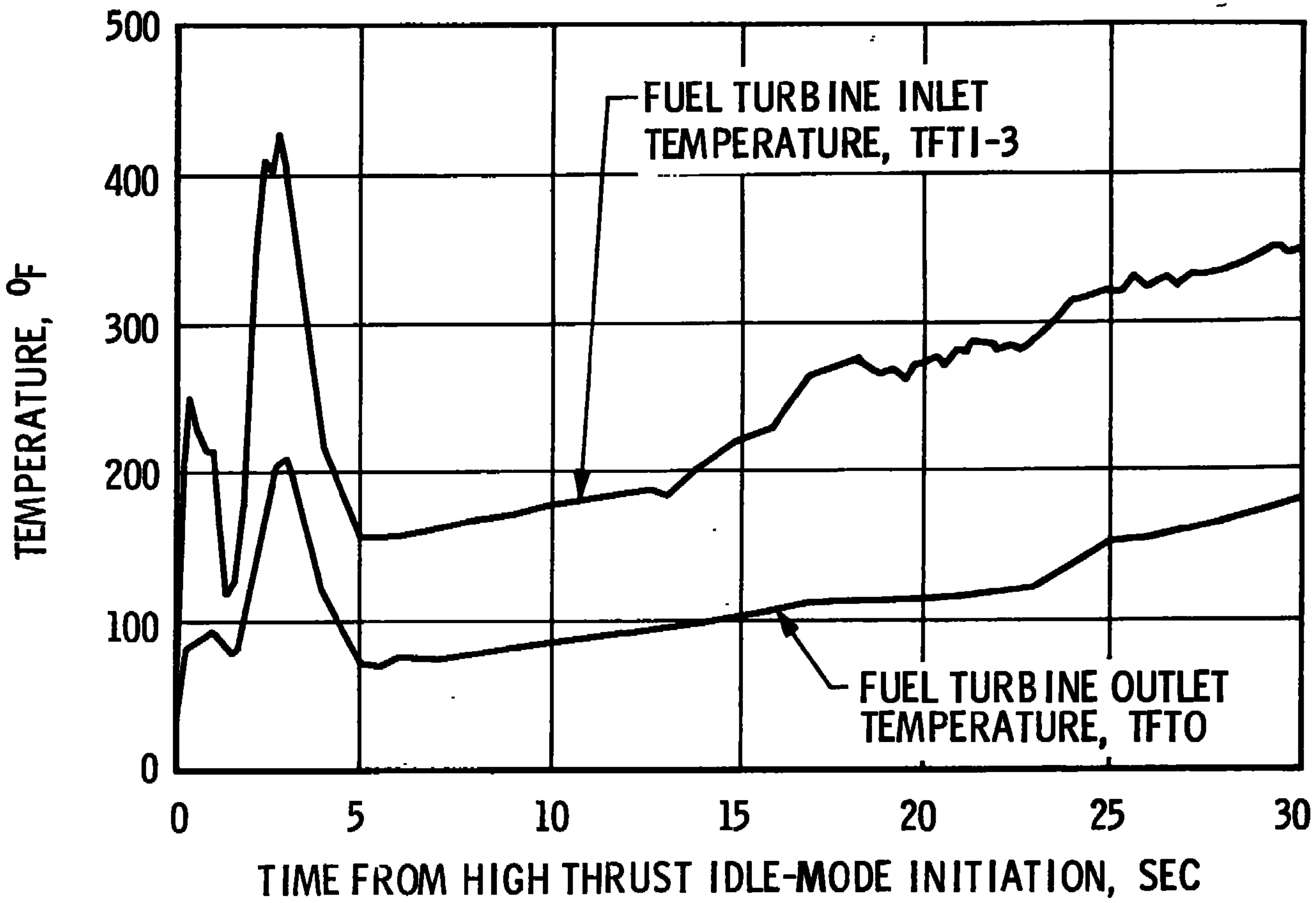


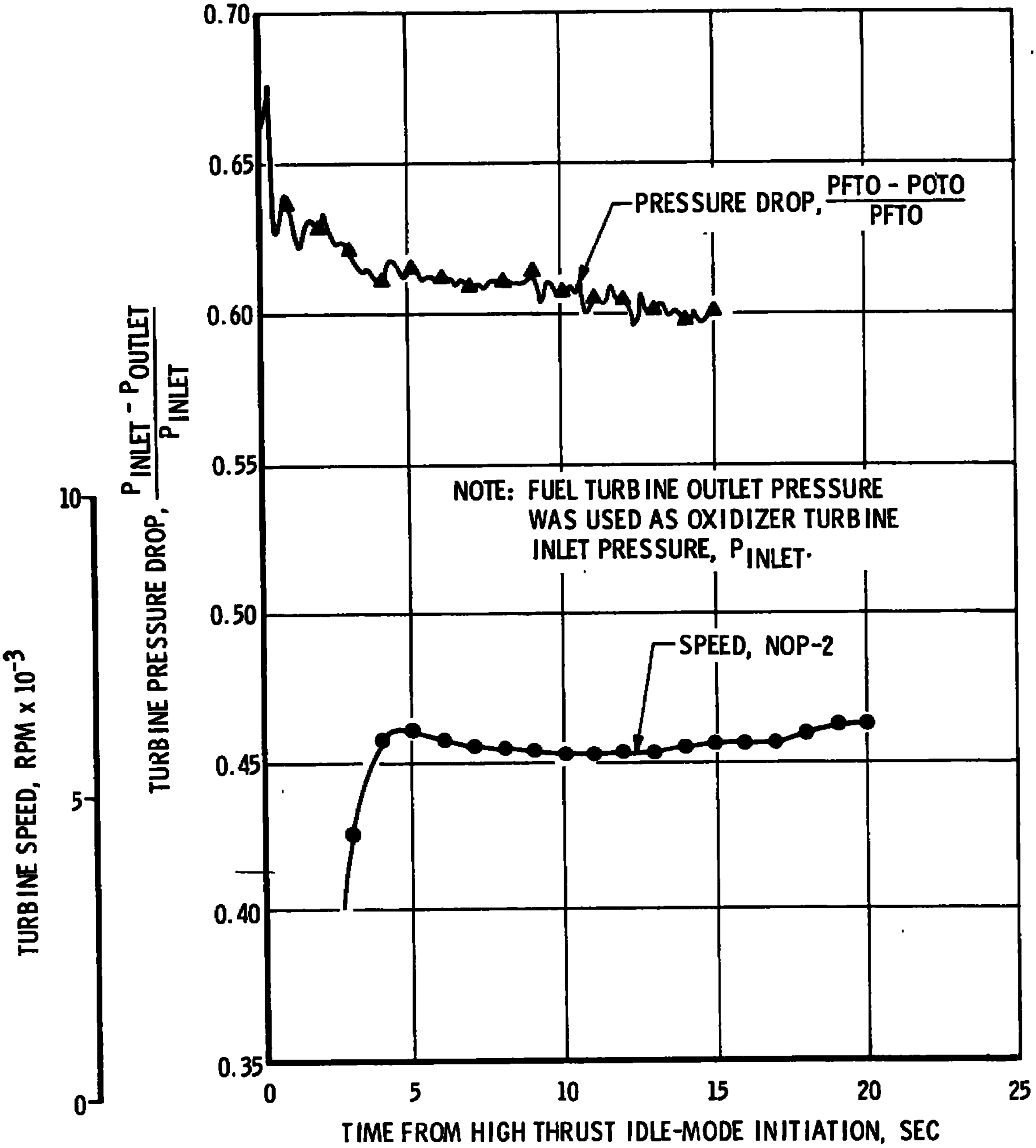
Fig. 38 Combustion Chamber Pressure, Firing 04B



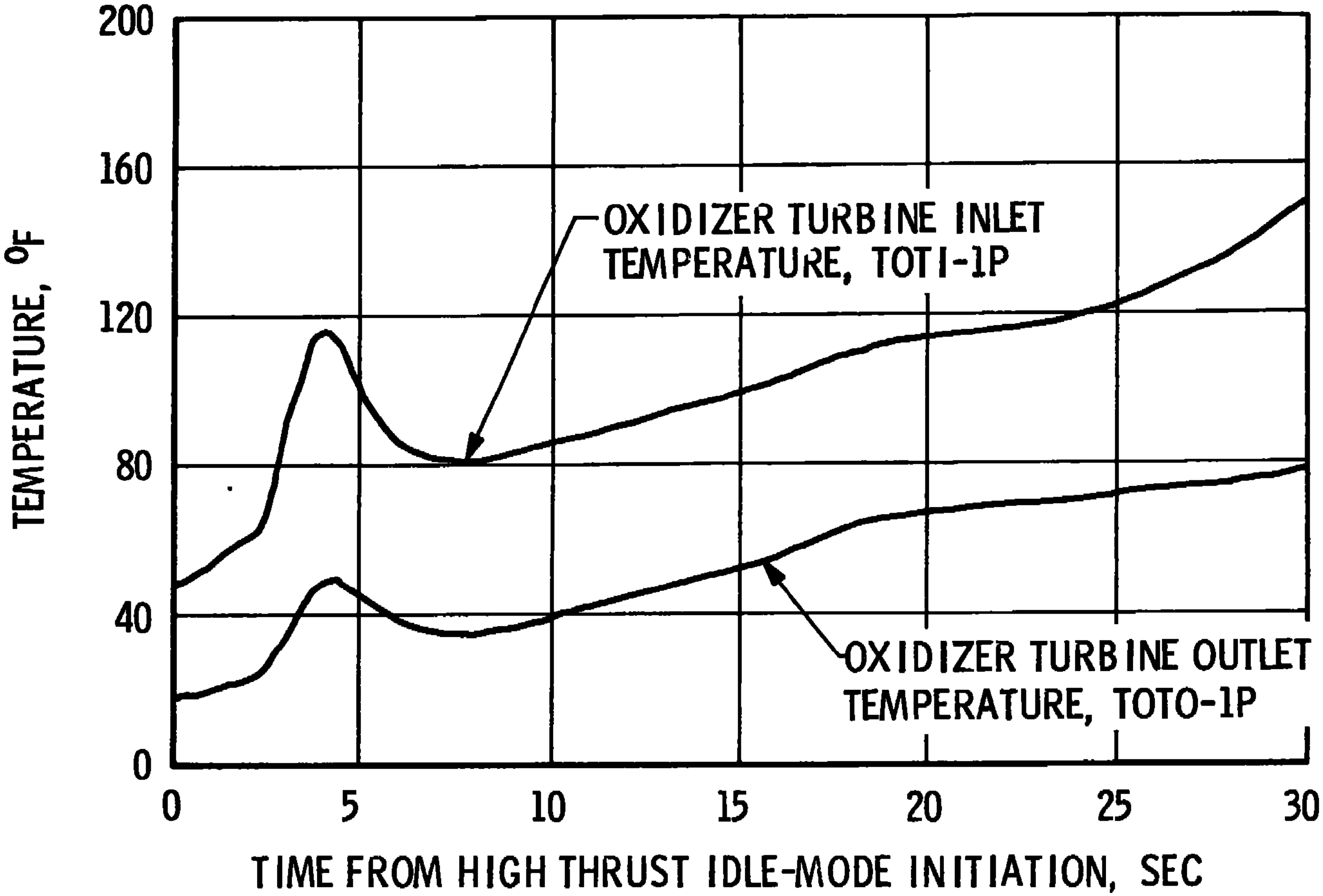
a. Fuel Turbine Speed and Pressure Drop
Fig. 39 Fuel and Oxidizer Turbine Performances, Firing 05B



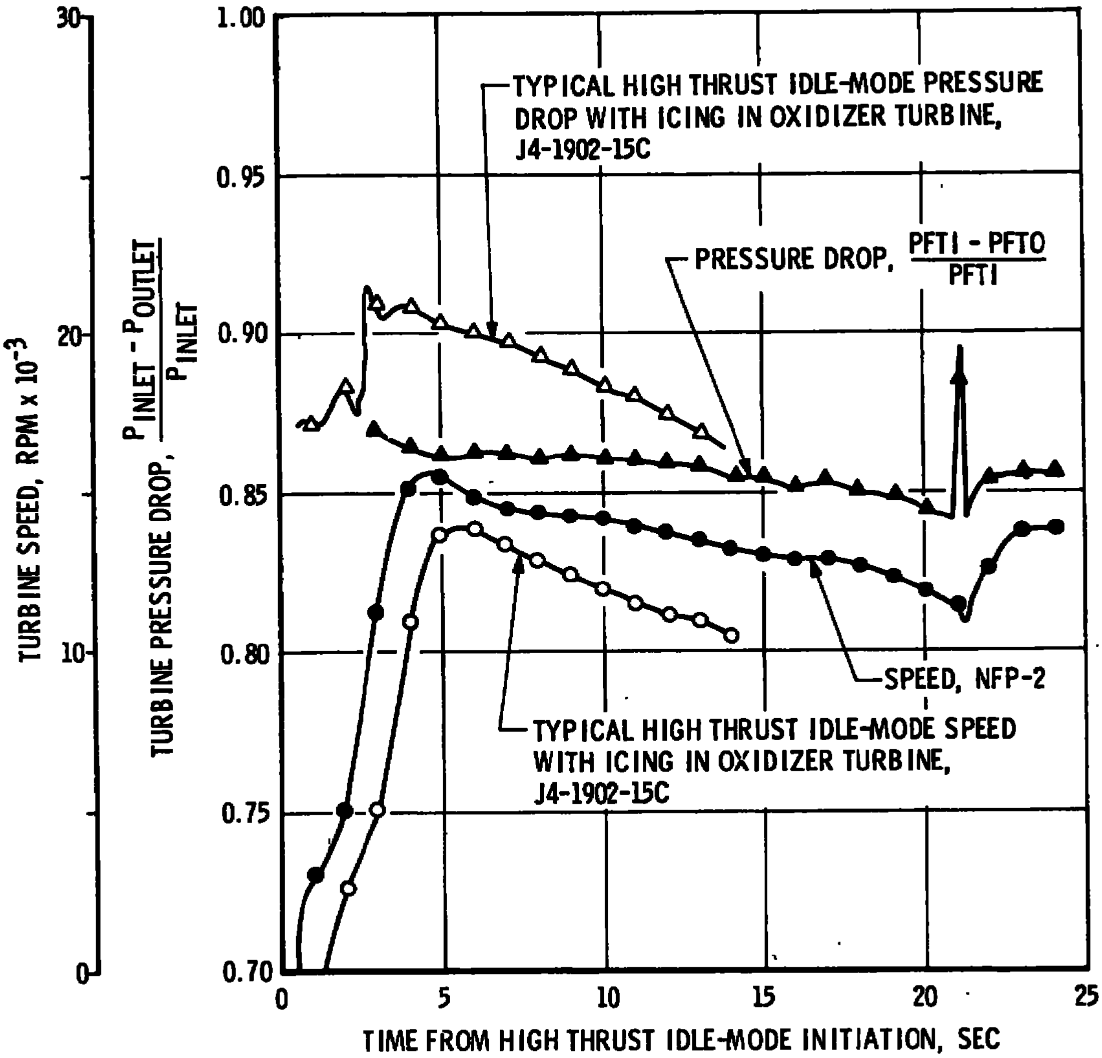
b. Fuel Turbine Inlet and Outlet Temperatures
Fig. 39 Continued



c. Oxidizer Turbine Speed and Pressure Drop
Fig. 39 Continued

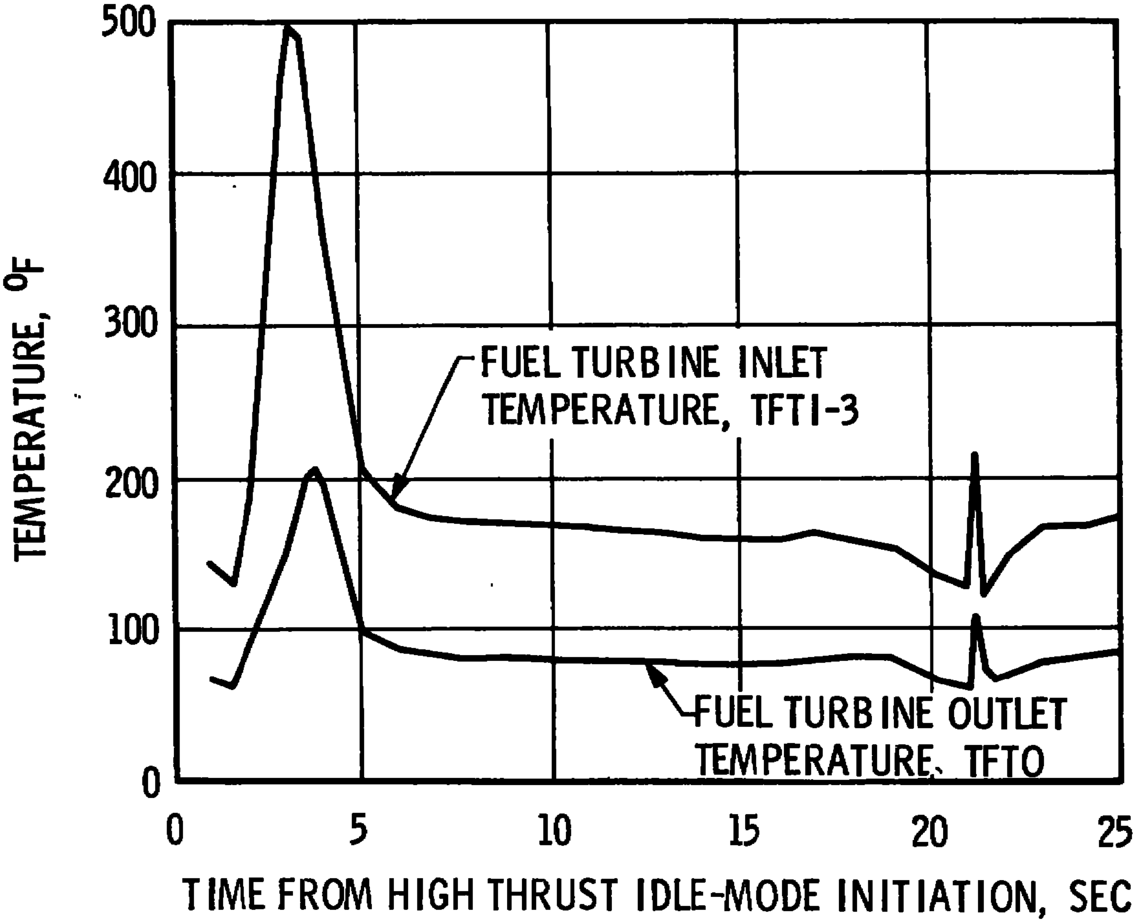


d. Oxidizer Turbine Inlet and Outlet Temperatures
Fig. 39 Concluded

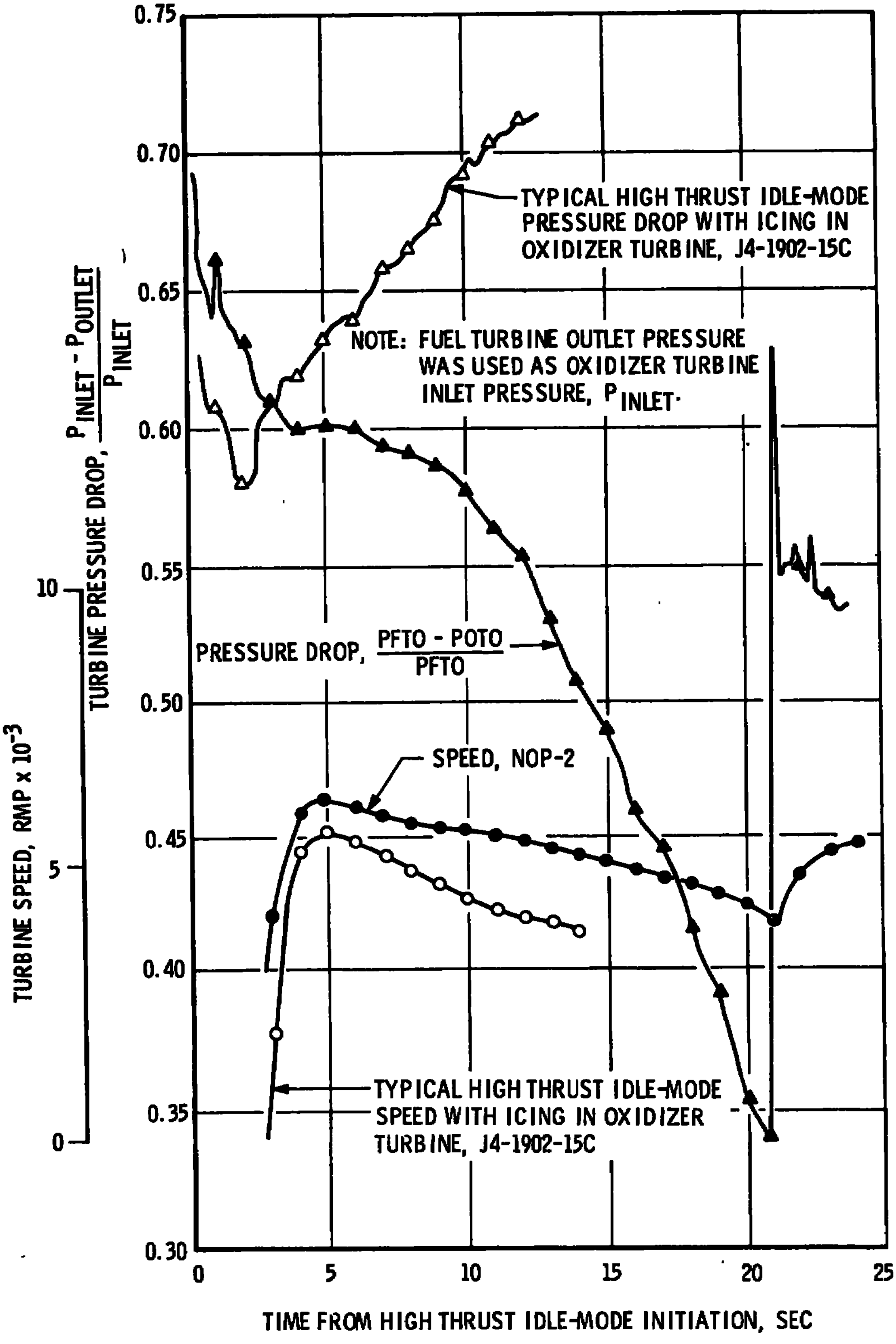


a. Fuel Turbine Speed and Pressure Drop

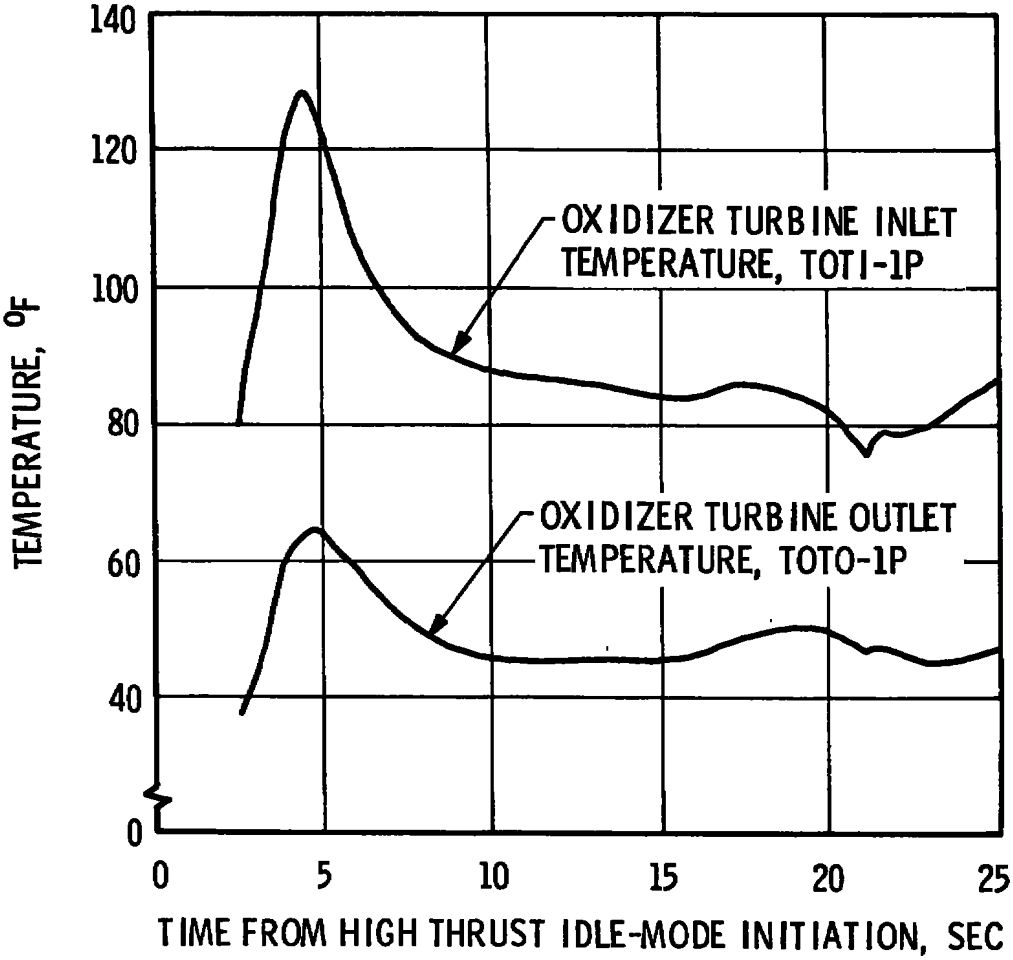
Fig. 40 Fuel and Oxidizer Turbine Performance, Firing 05C



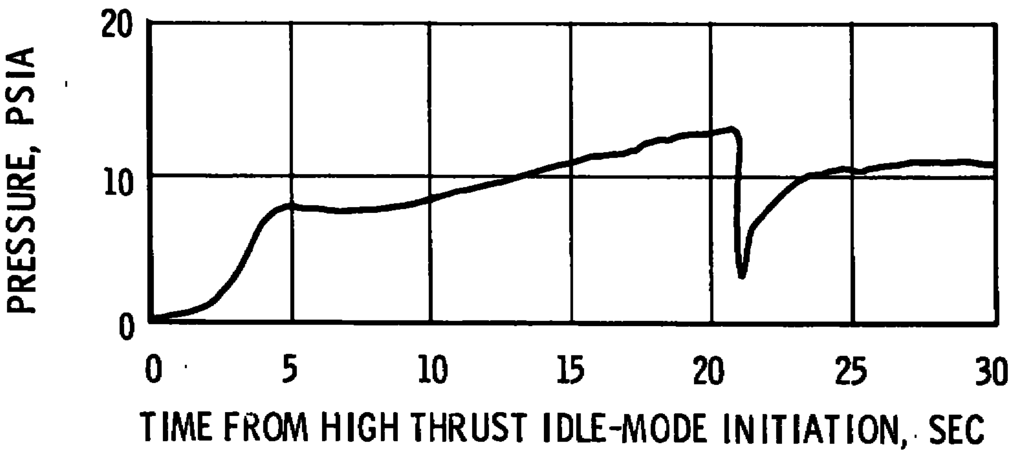
b. Fuel Turbine Inlet and Outlet Temperatures
Fig. 40 Continued



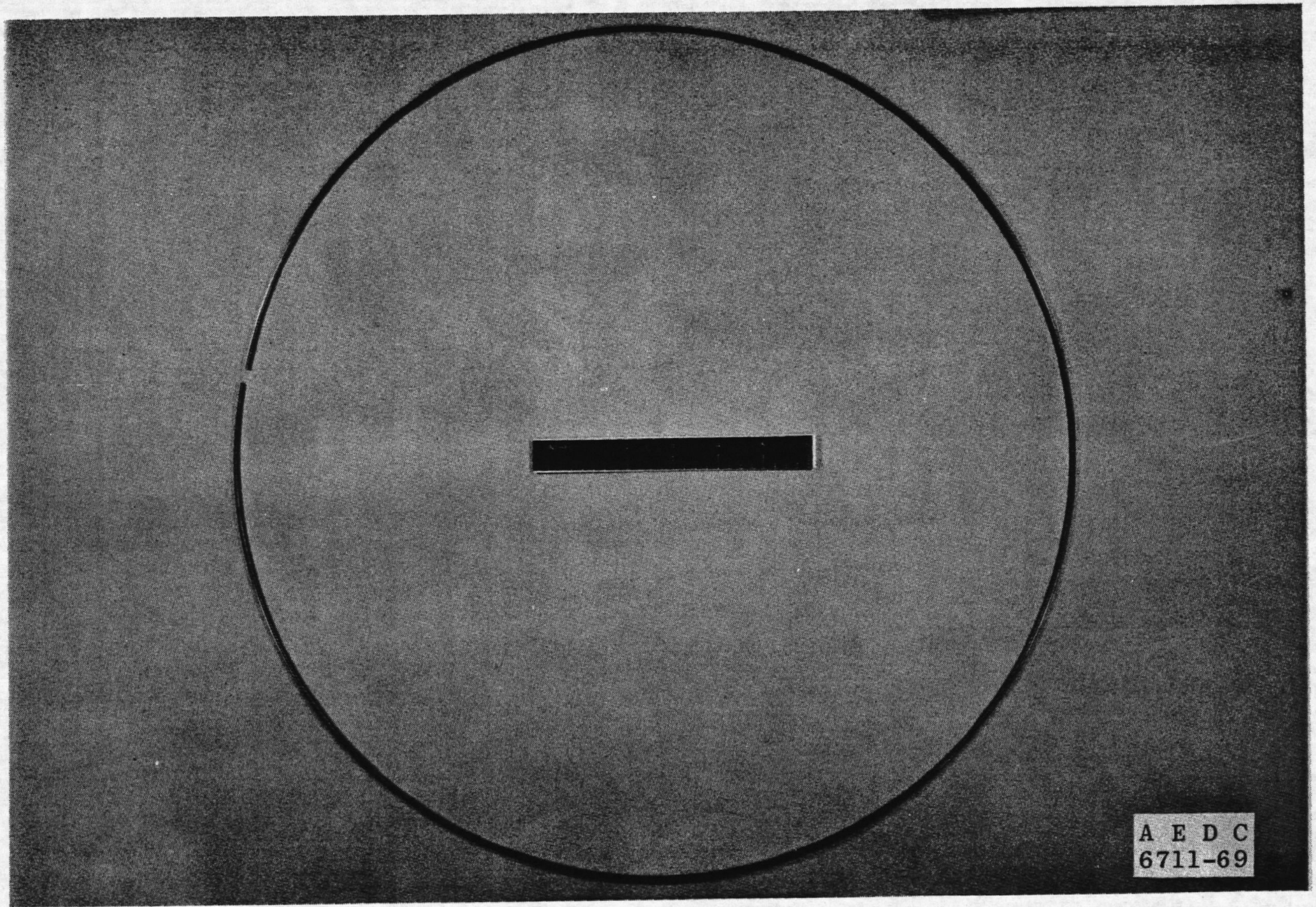
c. Oxidizer Turbine Speed and Pressure Drop
Fig. 40 Continued



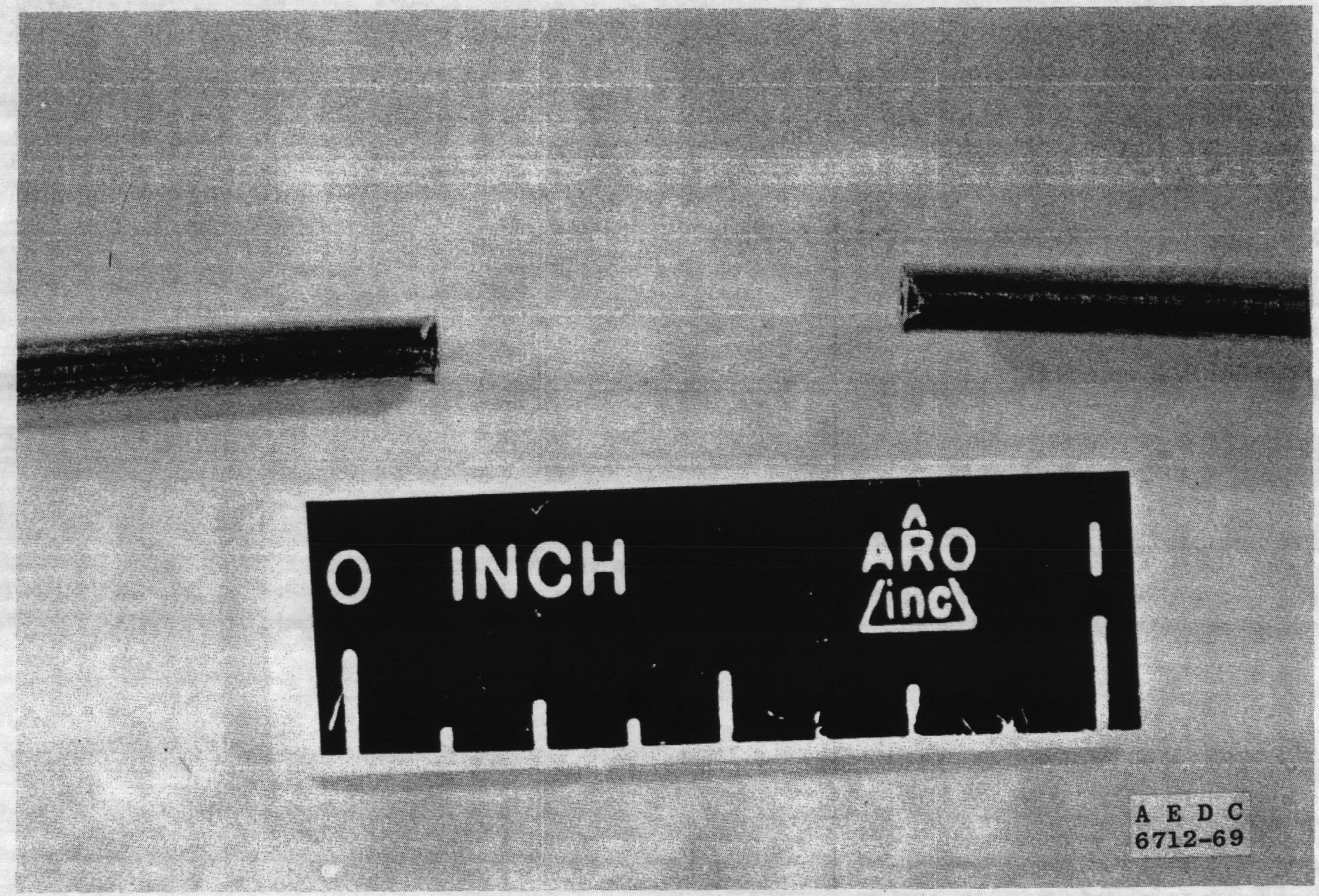
d. Oxidizer Turbine Inlet and Outlet Temperatures



e. Oxidizer Turbine Outlet Pressure, POTO
Fig. 40 Concluded



a. View of Injector Seal
Fig. 41 Injector Seal Photographs



b. Closeup of Broken Section of Injector Seal
Fig. 41 Concluded

TABLE I
MAJOR ENGINE COMPONENTS
(Effective Tests J4-1001-04 and J4-1001-05)

Part Name	P/N	S/N
Thrust chamber body assembly	99-210620	4094439
Thrust chamber injector assembly	XEOR-936648	4087384
Augmented spark igniter assembly	EWR113811-21	4901310
Ignition detector probe 1	3243-2	016
Ignition detector probe 2	3243-1	003X
Fuel turbopump assembly	99-461500-31	R004-1A
Oxidizer turbopump assembly	99-460430-21	S003-0A
Main fuel valve	99-411320-X3	8900881
Main oxidizer valve	99-411225-X4	8900929
Idle mode valve	99-411385	8900867
Thrust chamber bypass valve	99-411180-X2	8900806
Hot gas tapoff valve	99-557824-X2	8900847
Propellant utilization valve	99-251455-X5	8900911
Electrical control package	99-503670	4098176
Engine instrumentation package	99-704641	4097437
Pneumatic control package	99-558330	8900817
Restart control assembly	99-503680	4097867
Helium tank assembly	NA5-260212-1	0002
Oxidizer flowmeter	251216	4096874
Fuel flowmeter	251225	4096875
Fuel inlet duct assembly	409900-11	6631788
Oxidizer inlet duct assembly	409899	4052289
Fuel pump discharge duct	99-411082-7	439
Oxidizer pump discharge duct	99-411082-5	439
Thrust chamber bypass duct	99-411079	439
Fuel turbine exhaust bypass duct	307879-11	2143580
Hot gas tapoff duct	99-411080-51	7239768
Solid-propellant turbine starters manifold	99-210921-11	7216433
Heat exchanger and oxidizer turbine exhaust duct	307887	2142922
Crossover duct	307879-11	2143580

TABLE II
SUMMARY OF ENGINE ORIFICES

Orifice Name	Part	Diameter, in.	Test Effectivity	Comments
Augmented spark igniter fuel supply line	---	---	J4-1902-05	Open Line
Augmented spark igniter oxidizer supply line	99-652050	0.0999	J4-1902-05	---
Film coolant flow	---	0.581	J4-1902-08	EWR 121099
Thrust chamber bypass line	99-406384	1.500	J4-1902-17	EWR 121545
Oxidizer turbine bypass nozzle	99-210924	1.996	J4-1902-05	---
Film coolant venturi	---	1.027 inlet 0.744 throat	J4-1902-05	$C_D = 0.97$
Oxidizer idle-mode line	--- 99-411-92	--- 0.500	J4-1001-04 J4-1001-05	Open line EWR 121625

TABLE III
ENGINE MODIFICATIONS
(Between Tests J4-1001-04 and J4-1001-05)

Modification Number	Completion Date	Description of Modification
Test J4-1001-03 7/10/69		
EWR121609	7/1/69	Removal of oxidizer idle-mode line orifice
Test J4-1001-04 7/17/69		
EWR121625	7/22/69	Installation of 0.500-in.-diam oxidizer idle-mode line orifice
EWR121624	7/28/69	Main oxidizer valve first-stage open position changed to 13.5 deg
Test J4-1001-05 7/29/69		

TABLE IV
ENGINE COMPONENT REPLACEMENTS
(Between Tests J4-1001-04 and J4-1001-05)

Replacement	Completion Date	Component Replaced
Test J4-1001-03 7/10/69		
Electrical control assembly P/N 99-503670 S/N 4098176	6/26/69	P/N 99-503670-11 S/N 4097588
Test J4-1001-04 7/17/69		
None		
Test J4-1001-05 7/29/69		

TABLE V
ENGINE PURGE AND COMPONENT CONDITIONING SEQUENCE

Purge	Requirement	SPTS Installed	Air On	Propellant Drop	Engine Start	Cutoff	Coast Period	Propellant Drop	Restart	Cutoff (Last Firing)
Oxidizer dome and idle-mode compartment	Nitrogen, 600 ± 25 psia 100 to 200°F at customer connect panel (150 scfm)									15 min
Thrust chamber jacket, film coolant, and turbopump purges	Helium, 150 ± 25 psia 50 to 150°F at customer connect panel (125 scfm)		(**) (†)		(*)	15 min (**) (†)			(*)	15 min
SPTS conditioning	Nitrogen, -50 to 140°F	1, 2, and 3			Remaining SPTS Installed					
Main fuel valve conditioning	Helium, -300°F to ambient			††						

*Engine-supplied liquid-oxygen pump intermediate seal cavity purge
**Anytime facility water is on
†30 min before propellant drop
††Initiate MFV conditioning 30 min before engine start for those firings with temperature requirements

TABLE VI
SUMMARY OF TEST REQUIREMENTS AND RESULTS

FIRING NUMBER		J4-1001-04A		J4-1001-04B		J4-1001-05A		J4-1001-05B		J4-1001-05C	
		TARGET	ACTUAL	TARGET	ACTUAL	TARGET	ACTUAL	TARGET	ACTUAL	TARGET	ACTUAL
Firing Date/Time of Day		7/17/69	1244	7/17/69	1418	7/29/69	1154	7/29/69	1339	7/29/69	1439
Pressure Altitude at t-0, (Ref. 1)		100,000	85,000	100,000	98,500	100,000	94,000	100,000	99,000	100,000	101,000
Pre-Main-Stage Low Thrust Idle-Mode Duration, sec*		1.0	1.021	40.0	39.742	3.0	3.152	7.0	7.148	7.0	7.104
High Thrust Idle-Mode Duration, sec*		---	---	---	---	30.0	1.322	30.0	31.960	30.0	29.818
Main-Stage Duration, sec*		32.5	33.153	7.5	1.473	---	---	---	---	---	---
Fuel Pump Inlet Pressure at t-0, psia		33.0 ± 1.0	33.6	33.0 ± 1.0	32.9	33.0 ± 1.0	33.2	40.0 ± 1.0	40.3	33.0 ± 1.0	33.1
Fuel Pump Inlet Temperature at t-0, °F		---	-417.7	---	-321.9	---	-417.8	---	-416.5	---	-417.8
Fuel Tank Bulk Temperature at t-0, °F		-422.0 ± 0.4	-422.1	-422.0 ± 0.4	-422.2	-422.0 ± 0.4	-422.8	-422.0 ± 0.4	-422.8	-422.0 ± 0.4	-422.3
Oxidizer Pump Inlet Pressure at t-0, psia		39.0 ± 1.0	39.4	39.0 ± 1.0	37.8	39.0 ± 1.0	38.6	33.0 ± 1.0	32.8	39.0 ± 1.0	38.5
Oxidizer Pump Inlet Temperature at t-0, °F		---	-291.4	---	-282.2	---	-291.2	---	-291.4	---	-291.7
Oxidizer Tank Bulk Temperature at t-0, °F		-295.0 ± 0.4	-294.9	-295.0 ± 0.4	-295.3	-295.0 ± 0.4	-295.3	-295.0 ± 0.4	-295.2	-295.0 ± 0.4	-295.4
Fuel Injection Temperature at t-0, °F		---	99	---	96	---	72	---	64	---	44
Main Fuel Valve Temperature at t-0, °F		-100^{+0}_{-50}	-115	---	107	---	98	---	89	---	54
Augmented Spark Igniter Ignition Detected, sec*		---	0.612	---	0.456	---	0.578	---	1.028	---	0.615
Propellant Utilization Valve Position at t-0, (Ref. t-0)		Null	Null	Null	Null	Null	Null	Null	Null	Null	Null
Oxidizer Pump Bearing Coolant Temperature at t-0, °F		---	-292	-100	-126	---	-287	---	-288	---	-288
Helium Tank Conditions at t-0,	Pressure, psia	3450^{+0}_{-200}	3319	---	2928	3450^{+0}_{-200}	3371	---	2971	---	2779
	Temperature, °F	---	123	---	97	---	115	---	85	---	77
Solid Propellant Turbine Starter	Part Number	99803527-11		99803527-11		---	---	---	---	---	---
	Serial Number	RT000003		RT000004		---	---	---	---	---	---
	Temperature at t-0, °F	50 ± 10	32	50 ± 10	73	---	---	---	---	---	---
	Burn Time, sec	---	2.284	---	2.286	---	---	---	---	---	---
	Maximum Chamber Pressure, psia	---	3375	---	3457	---	---	---	---	---	---

*Data reduced from oscillogram

TABLE VII
ENGINE VALVE TIMINGS

Test J4-1001-	Firing	Start																	
		Main Fuel Valve			Idle-Mode Oxidizer Valve			Hot Gas Tapoff Valve			Main Oxidizer Valve First Stage			Main Oxidizer Valve Second Stage			Thrust Chamber Bypass Valve		
		Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec
04	A	0	0.052	0.061	0	0.123	0.042	1.021	0.165	0.083	1.021	0.086	0.035	2.916	0.210	0.834	2.916	0.190	1.080
	B	0	0.049	0.053	0	0.114	0.040	39.742	0.169	0.090	39.742	0.081	0.030	---	---	---	---	---	---
	Final Sequence	0	0.048	0.061	0	0.114	0.042	1.015	0.150	0.080	1.015	0.082	0.037	2.911	0.147	0.795	2.911	0.180	0.900
05	A	0	0.048	0.053	0	0.112	0.042	0	3.152	0.092	1.022	0.083	0.046	---	---	---	---	---	---
	B	0	0.050	0.053	0	0.117	0.041	0	7.148	0.094	5.335	0.083	0.045	---	---	---	0	22.342	0.990
	C	0	0.050	0.050	0	0.120	0.040	0	7.104	0.089	4.576	0.085	0.040	---	---	---	0	22.260	0.990
	Final Sequence	0	0.045	0.065	0	0.115	0.043	0	3.130	0.091	1.020	0.079	0.043	---	---	---	0	18.315	0.820

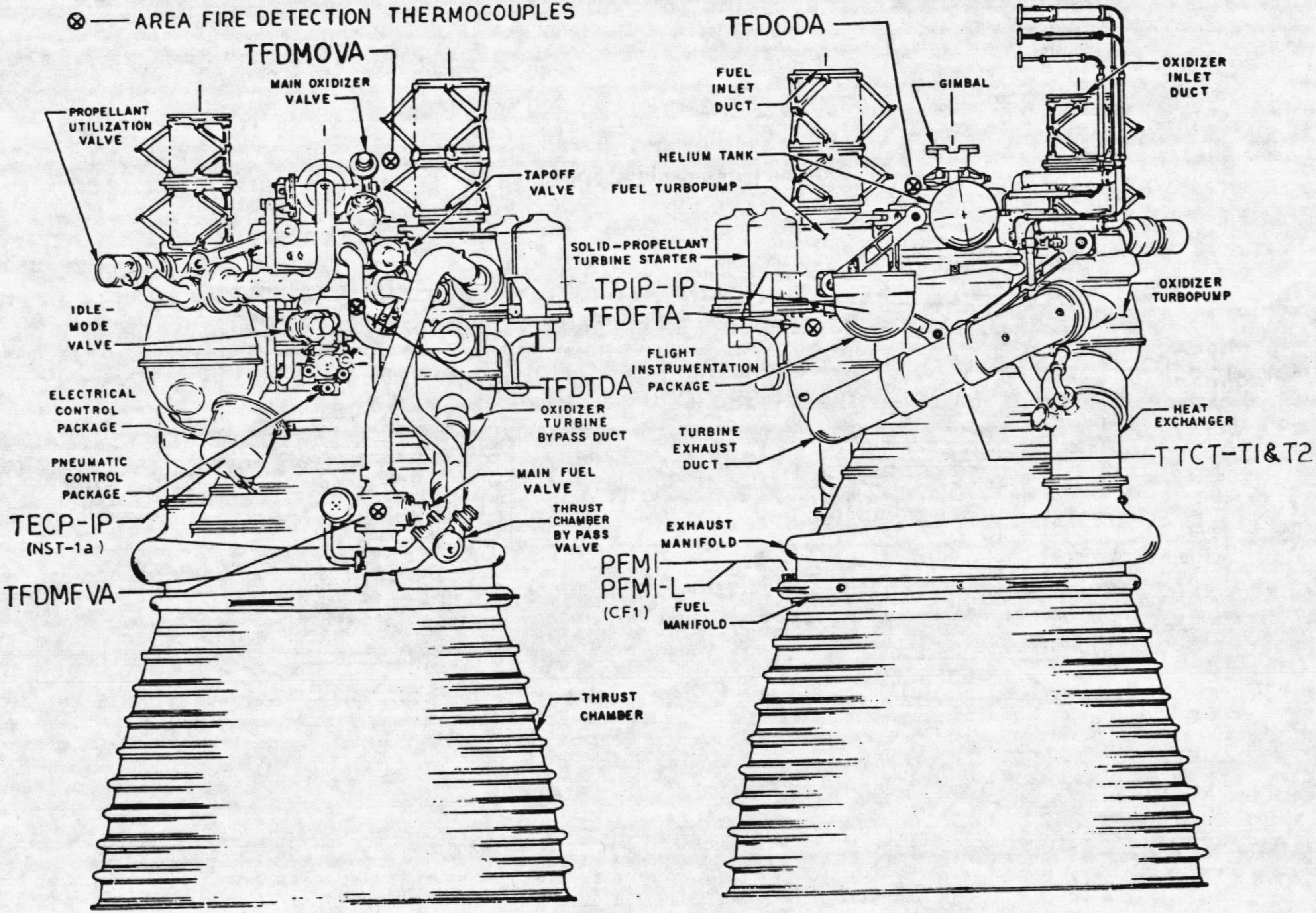
Test J4-1001-	Firing	Shutdown														
		Main Oxidizer Valve			Hot Gas Tapoff Valve			Main Fuel Valve			Idle-Mode Oxidizer Valve			Thrust Chamber Bypass Valve		
		Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Closing Signal	Valve Delay Time, sec	Valve Closing Time, sec	Time of Opening Signal	Valve Delay Time, sec	Valve Opening Time, sec
04	A	34.165	0.093	0.150	34.165	0.073	0.220	34.165	0.083	0.312	34.165	0.083	0.140	34.165	0.333	0.210
	B	41.215	0.041*	0.036*	41.215	0.072	0.235	41.215	0.077	0.254	41.215	0.065	0.122	---	---	---
	Final Sequence	10.475	0.089	0.146	10.475	0.078	0.250	10.475	0.083	0.255	10.475	0.075	0.108	10.475	0.298	0.227
05	A	4.474	0.040*	0.037*	4.474	0.195	0.225	4.474	0.071	0.250	4.474	0.070	0.155	---	---	---
	B	39.108	0.044*	0.044*	39.108	0.230	0.250	39.108	0.077	0.255	39.108	0.073	0.155	39.108	0.347	0.230
	C	36.922	0.040*	0.045*	36.922	0.225	0.250	36.922	0.071	0.265	36.922	0.066	0.158	26.922	0.360	0.250
	Final Sequence	22.650	0.042*	0.035*	22.650	0.210	0.235	22.650	0.070	0.255	22.650	0.066	0.110	22.650	0.320	0.220

*Main oxidizer valve first stage only

NOTES: 1. All valve signal times are referenced to t-0.
2. Valve delay time is the time required for initial valve movement after the valve open or closed solenoid has been energized
3. Final sequence check is conducted without propellants and within 12 hr before testing.
4. Data are reduced from oscillogram.

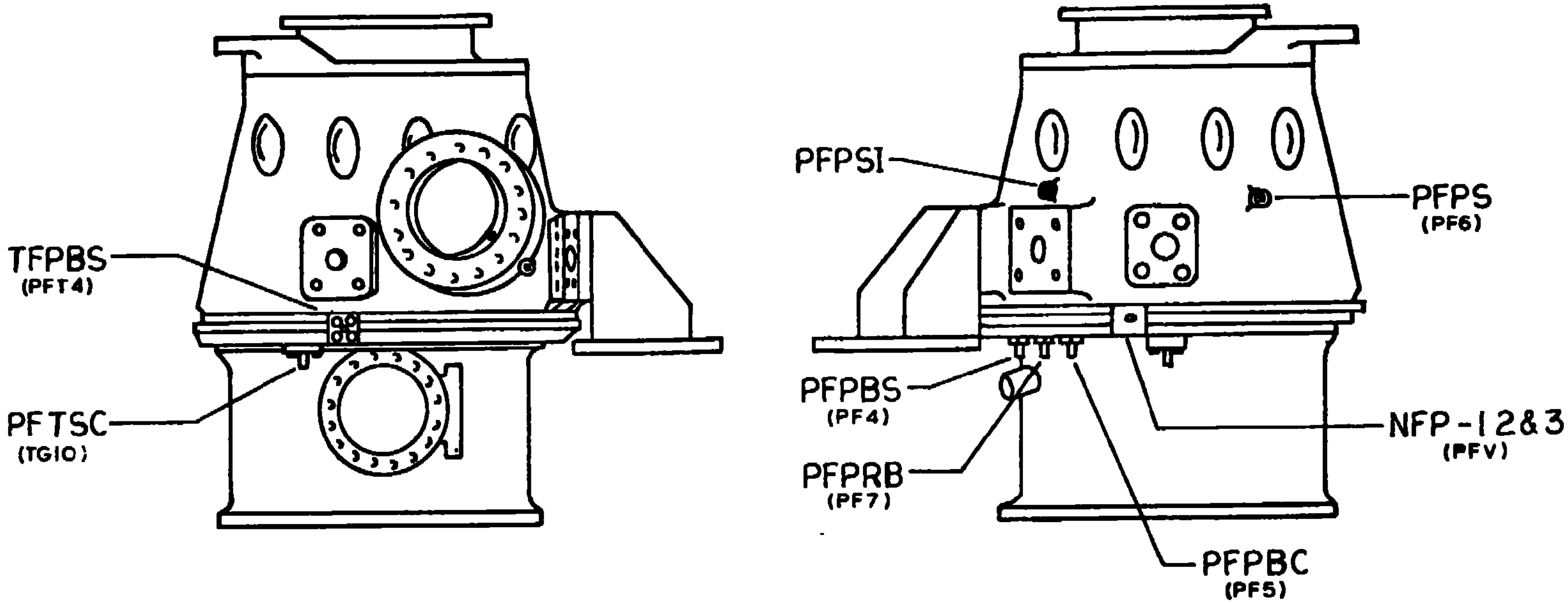
APPENDIX III
INSTRUMENTATION

The instrumentation for AEDC tests J4-1001-04 and J4-1001-05 is tabulated in Table III-1. The location of selected major engine instrumentation is shown in Fig. III-1.

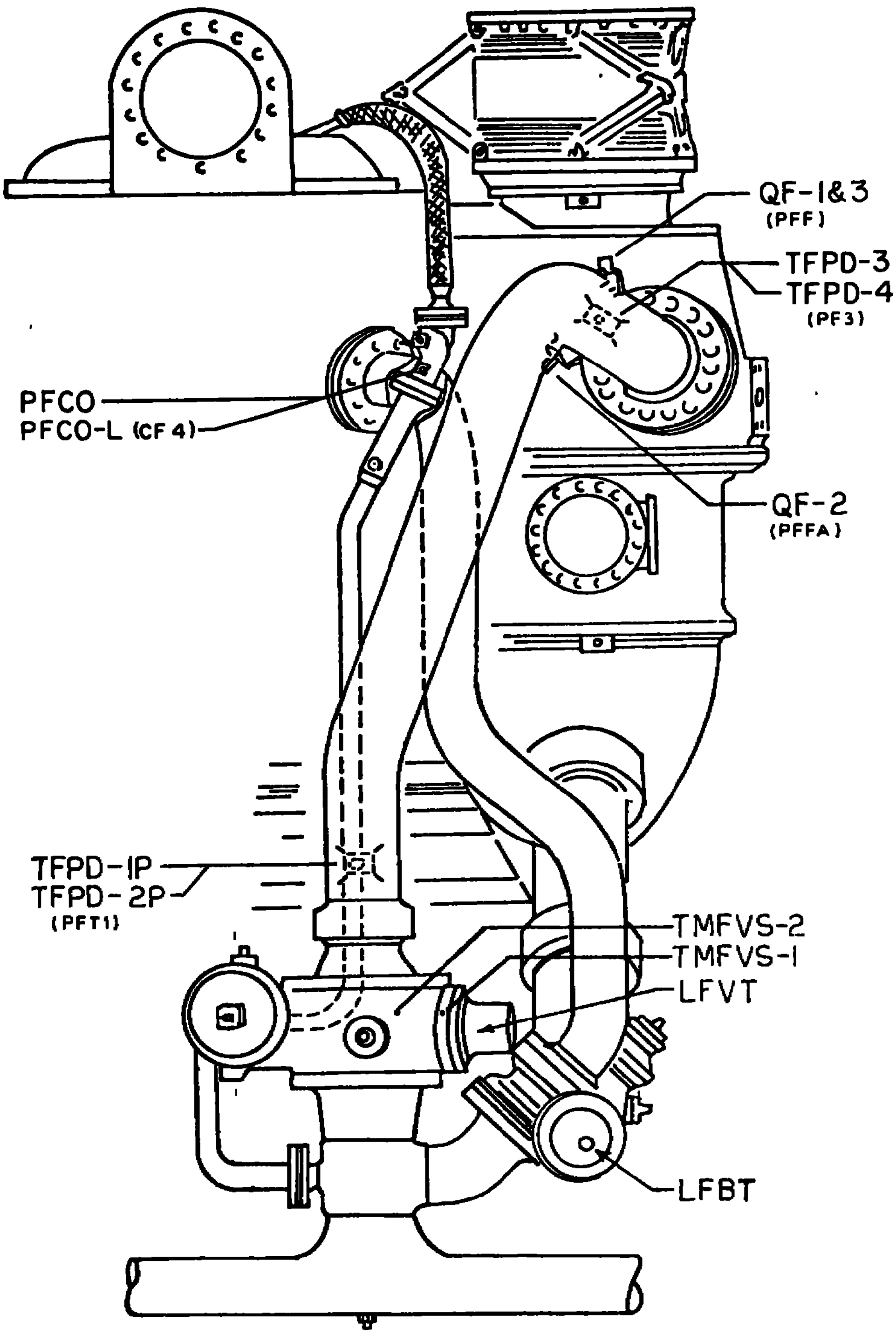


a. General Arrangement

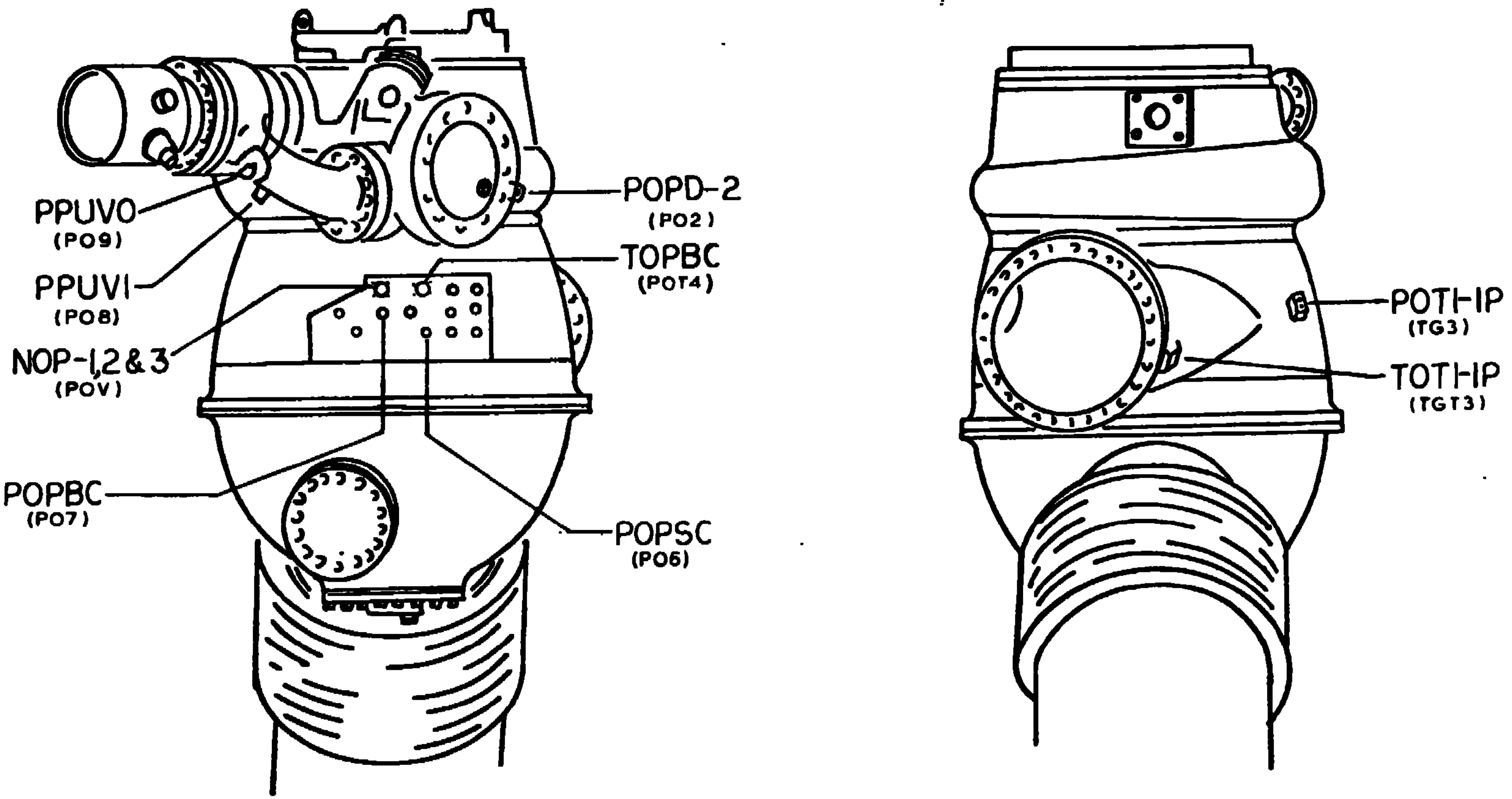
Fig. III-1 Selected Sensor Locations



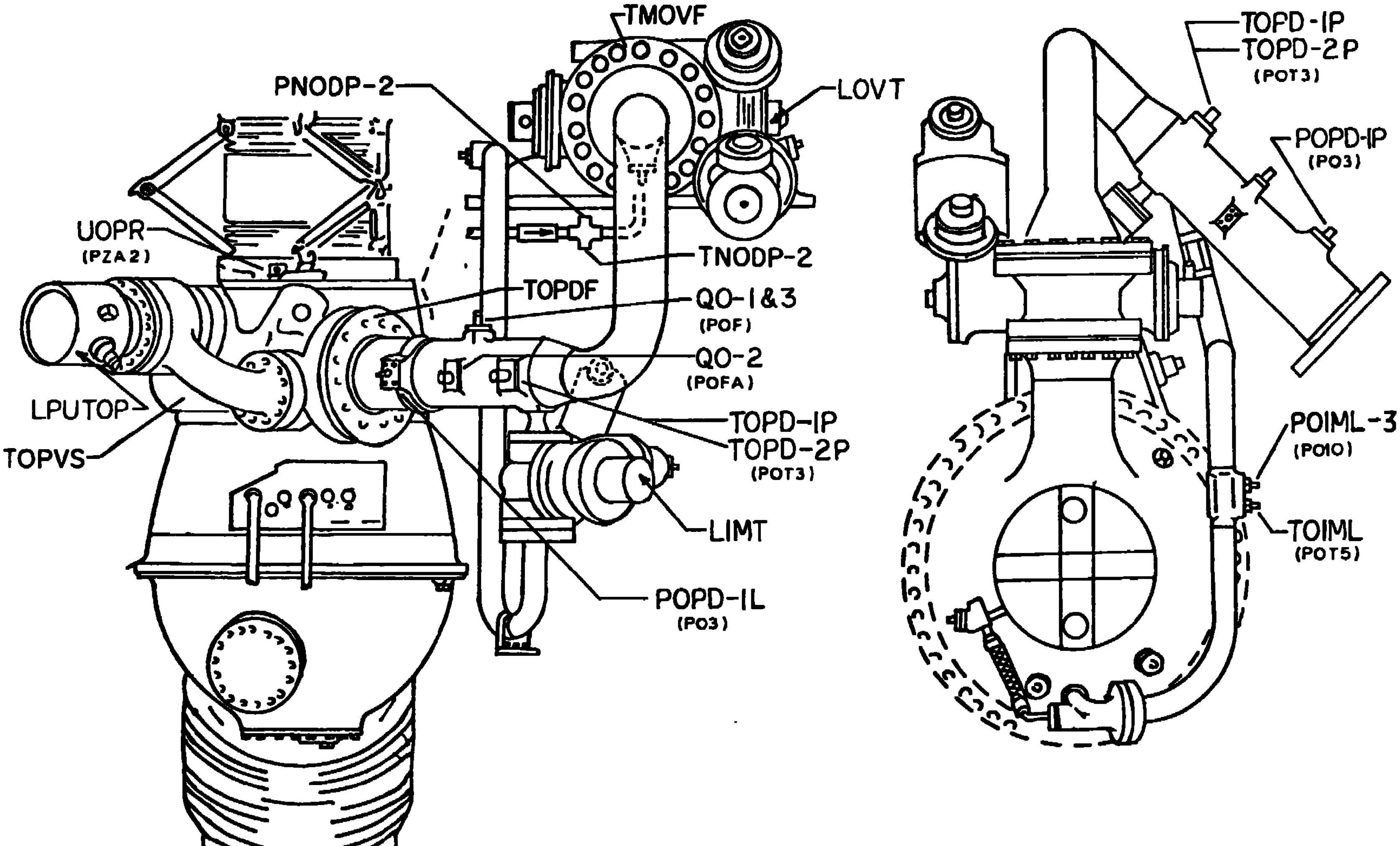
b. Fuel Turbopump Sensor Locations
Fig. III-1 Continued



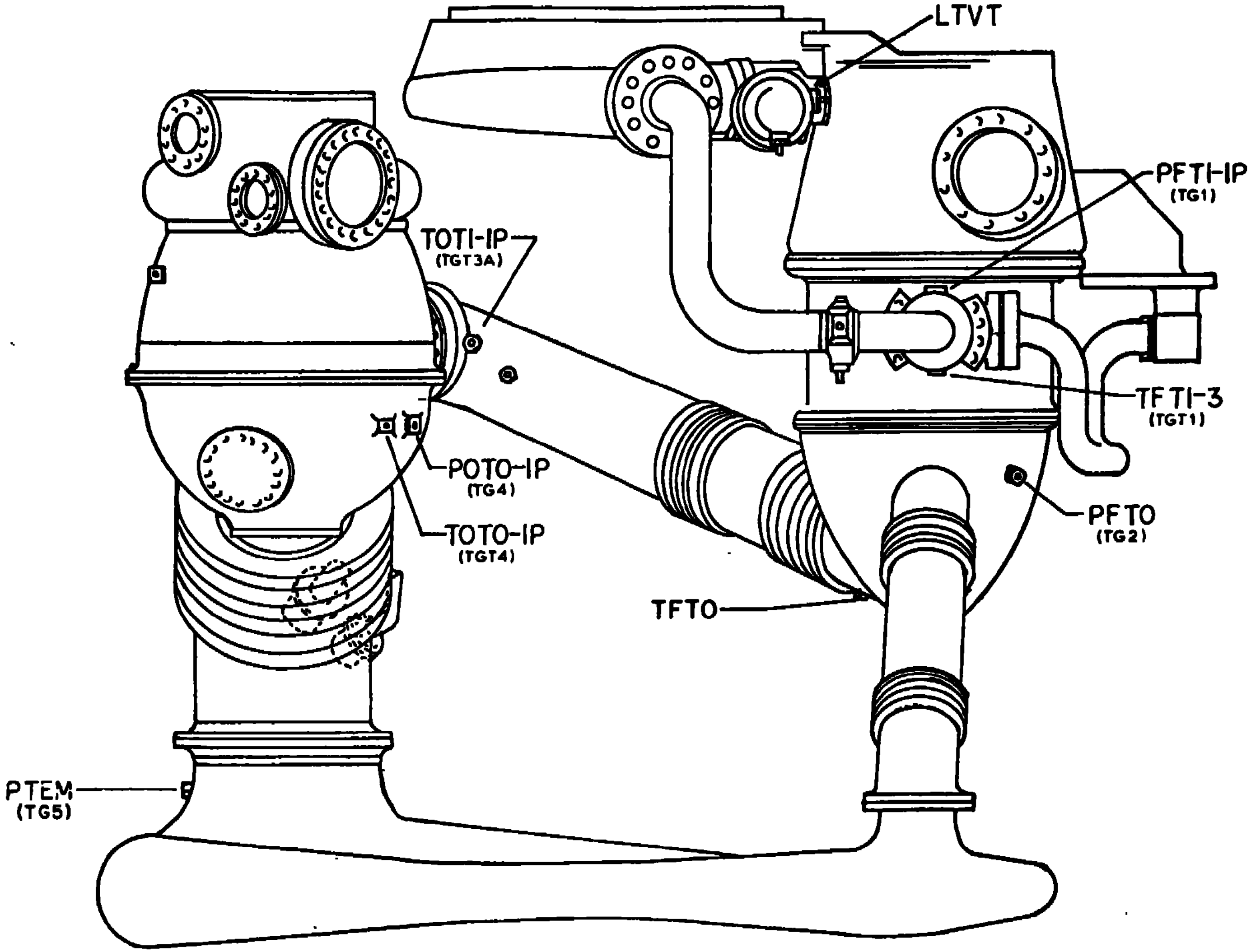
c. Fuel System Sensor Locations
Fig. III-1 Continued



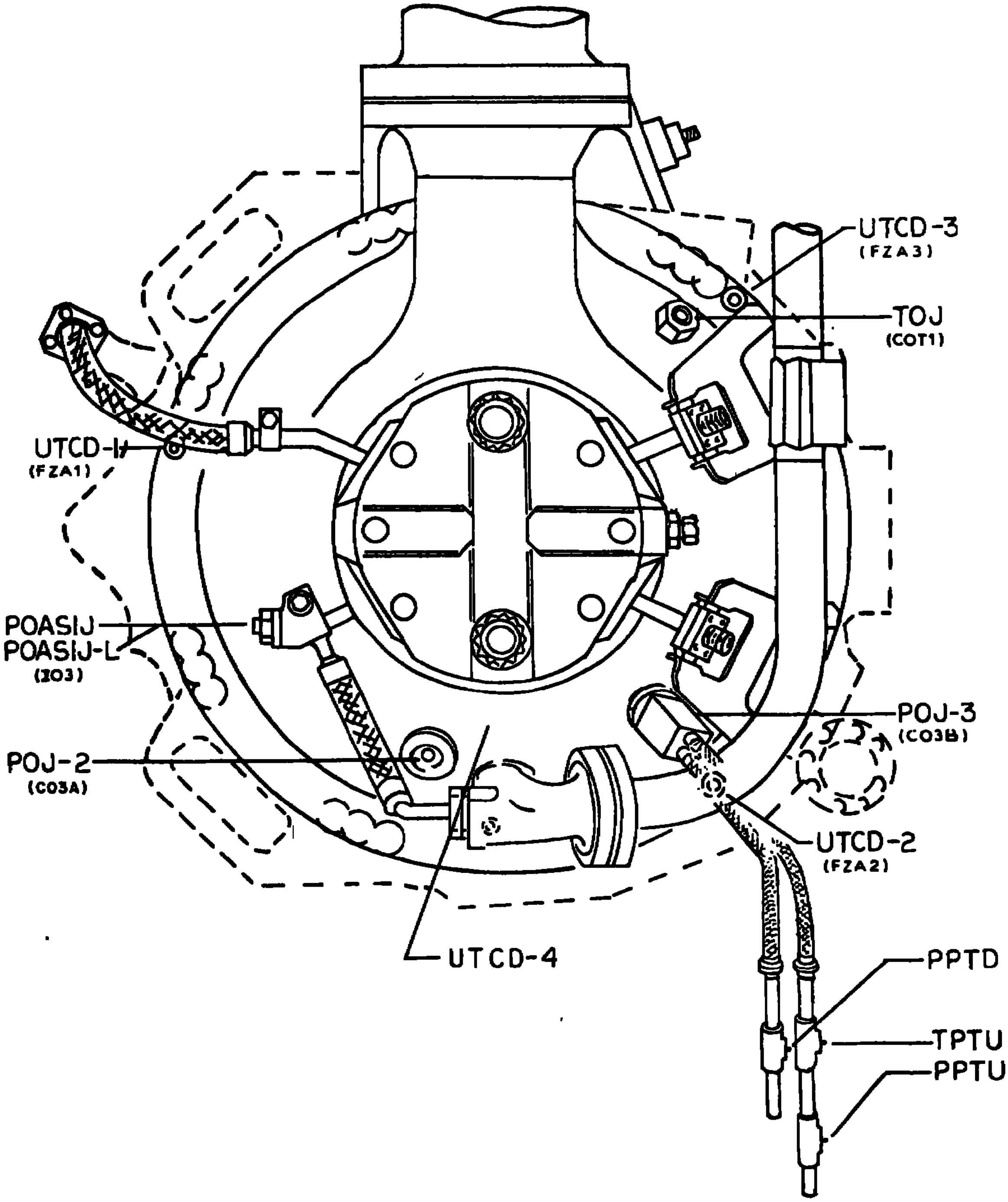
d. Oxidizer Turbopump Sensor Locations
Fig. III-1 Continued



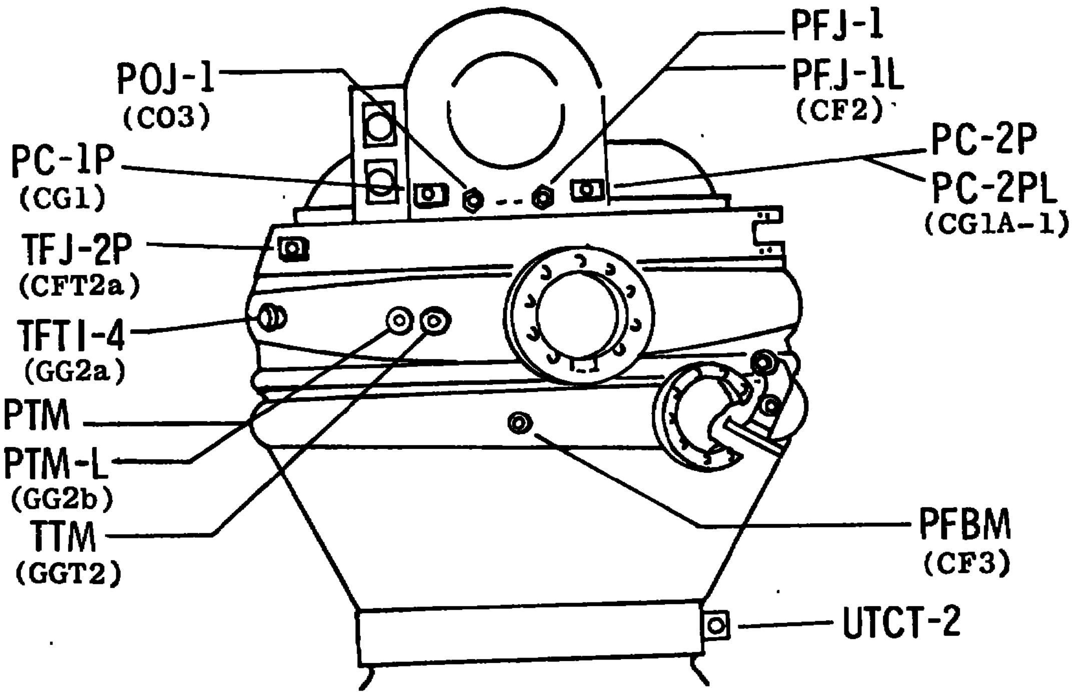
e. Oxidizer System Sensor Locations
Fig. III-1 Continued

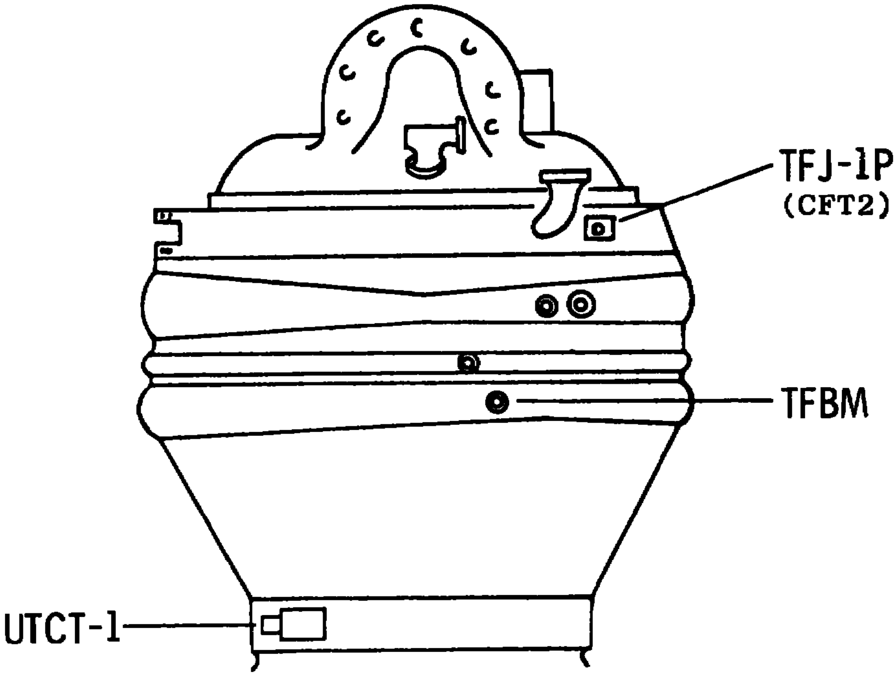


f. Turbine Exhaust Systems Sensor Locations
Fig. III-1 Continued

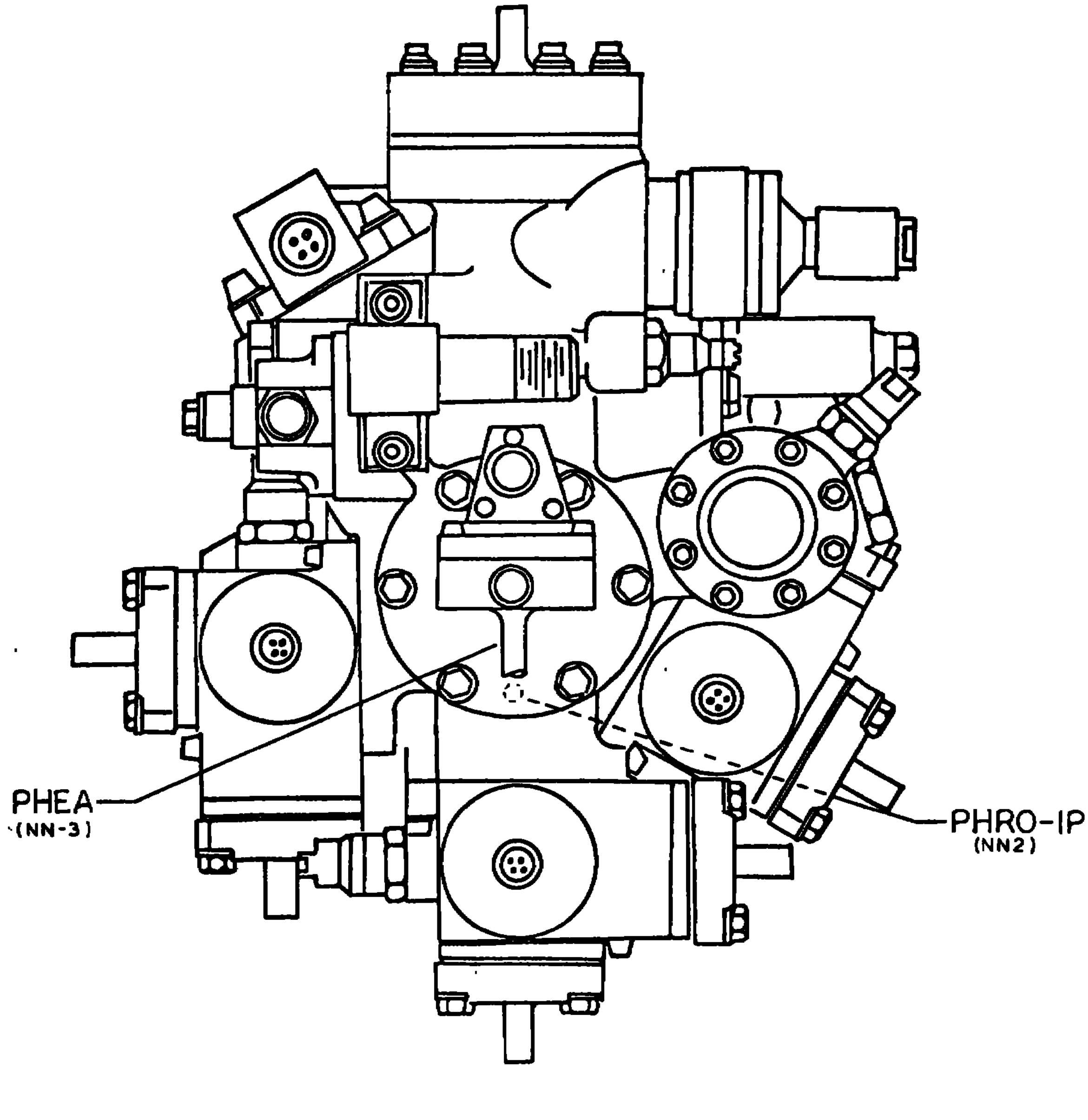


g. Thrust Chamber Injector Sensor Locations
Fig. III-1 Continued

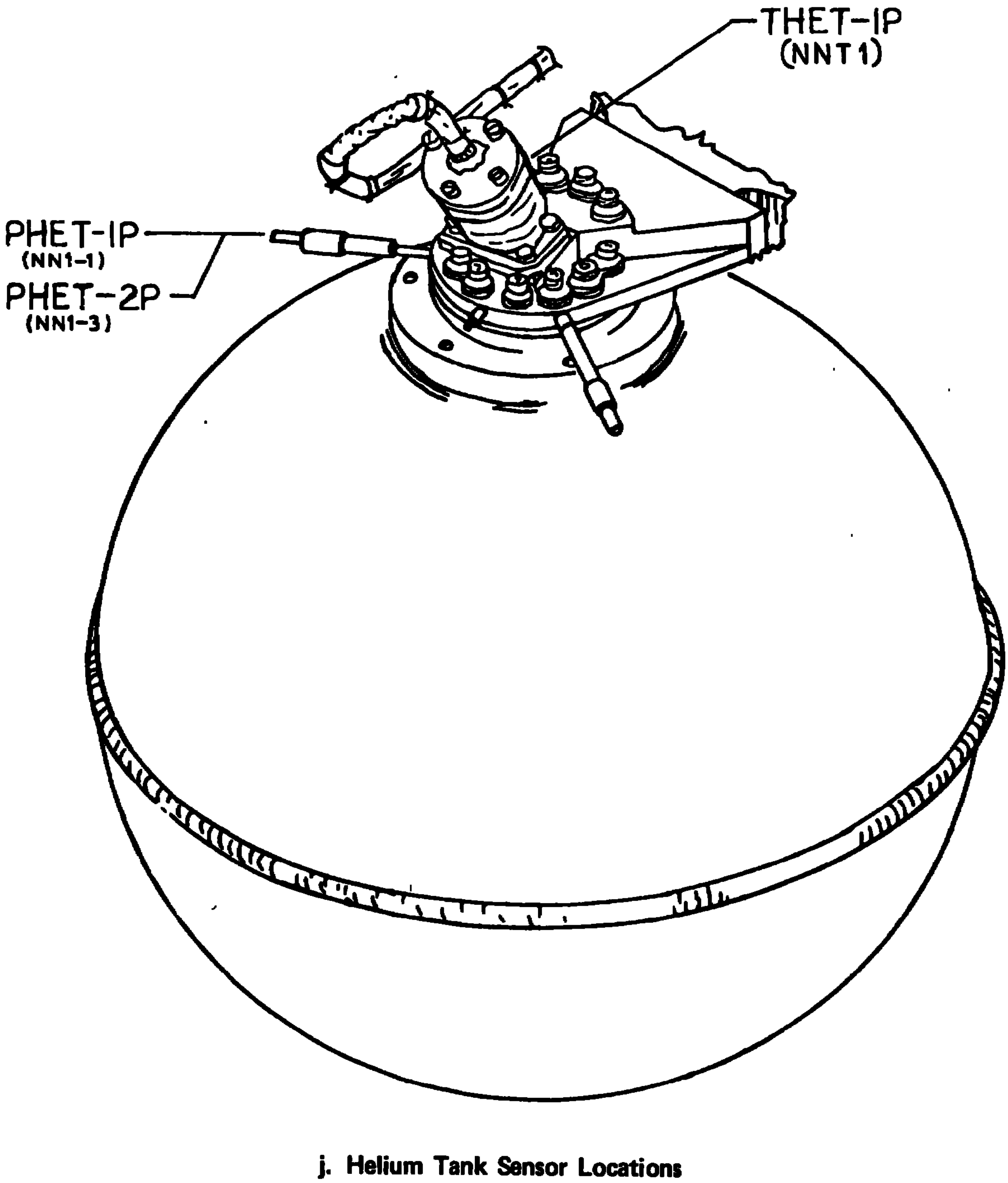




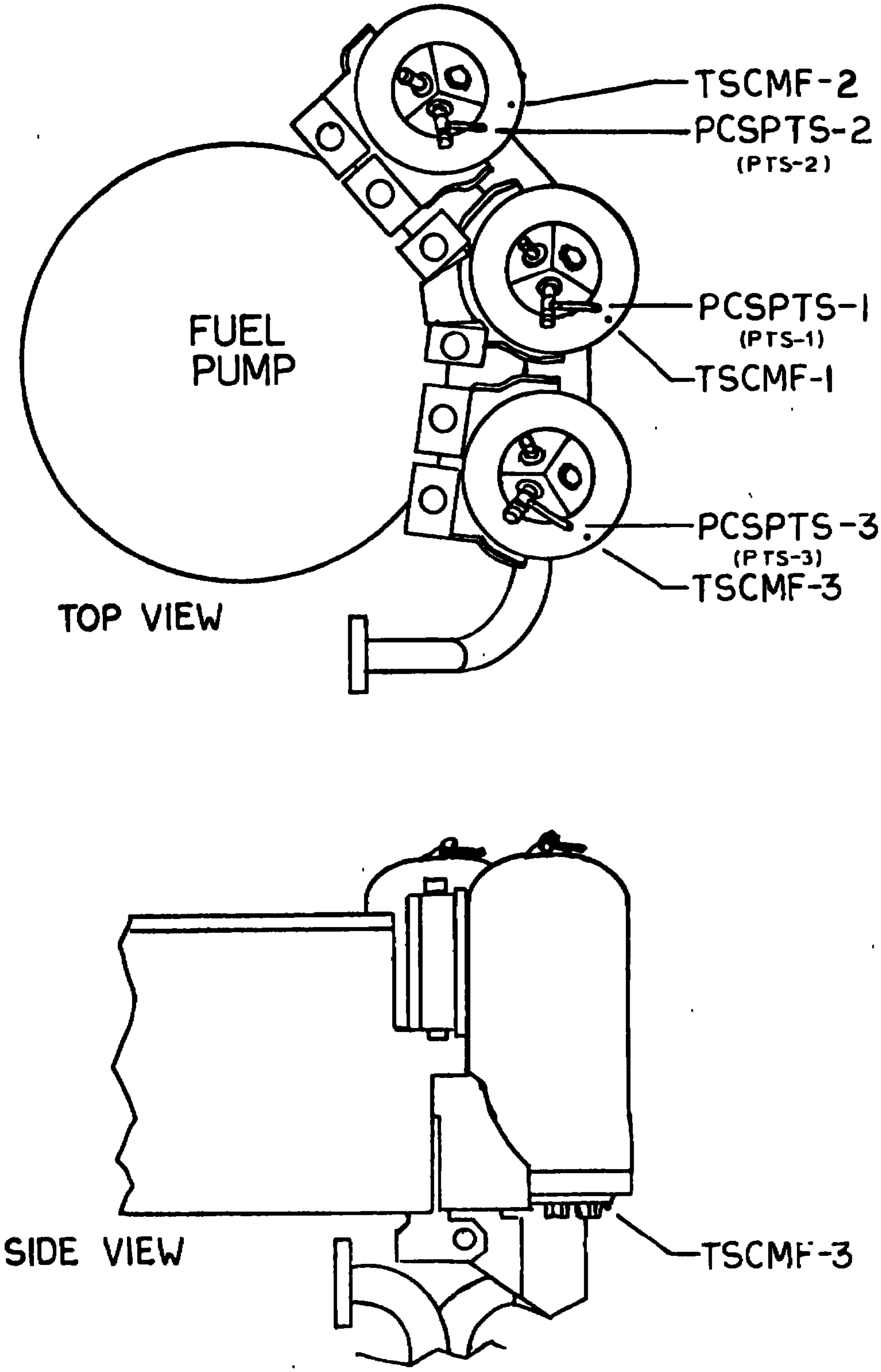
h. Thrust Chamber Sensor Locations
Fig. III-1 Continued



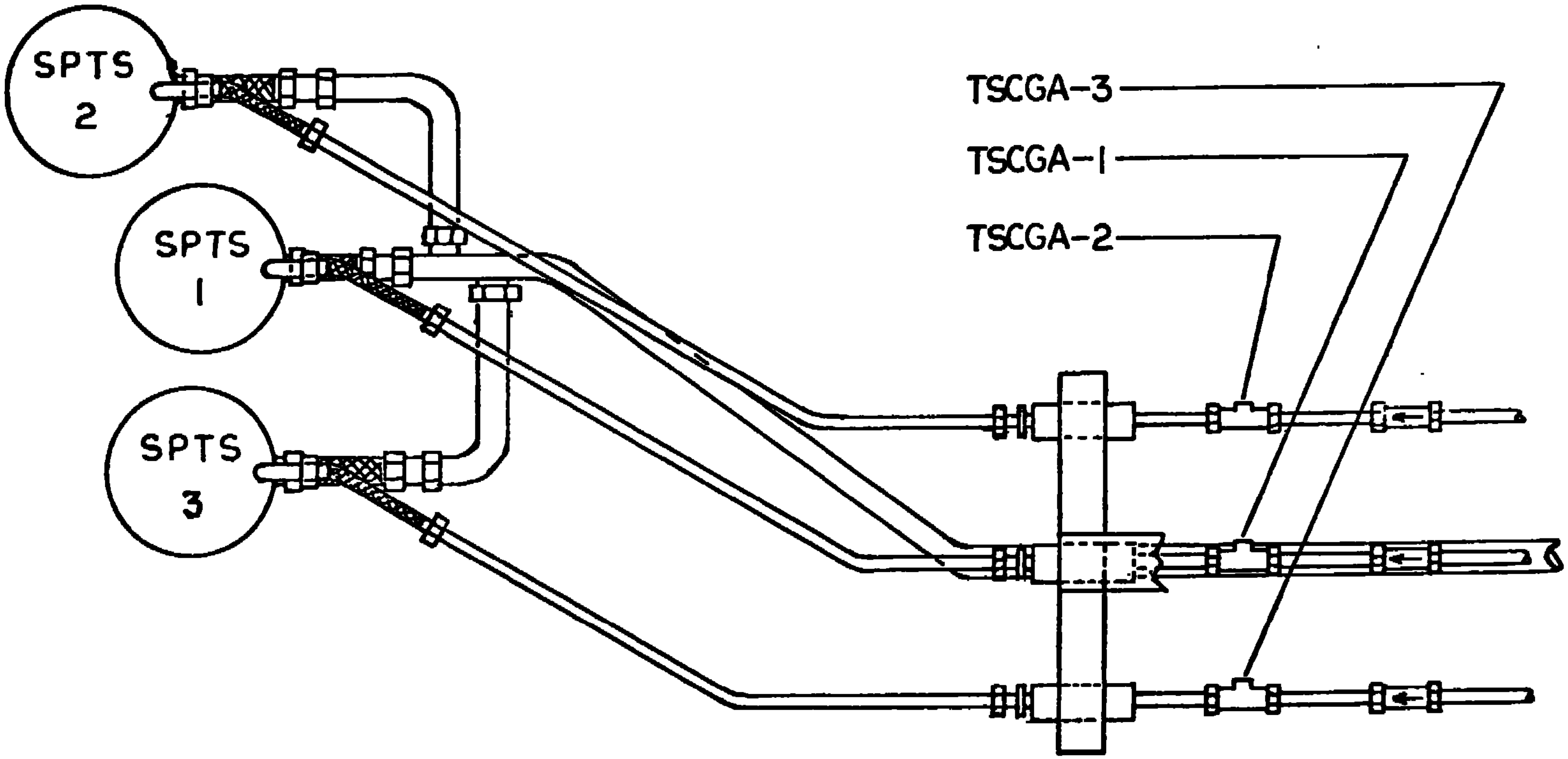
i. Pneumatic Control Package Sensor Locations
Fig. III-1 Continued



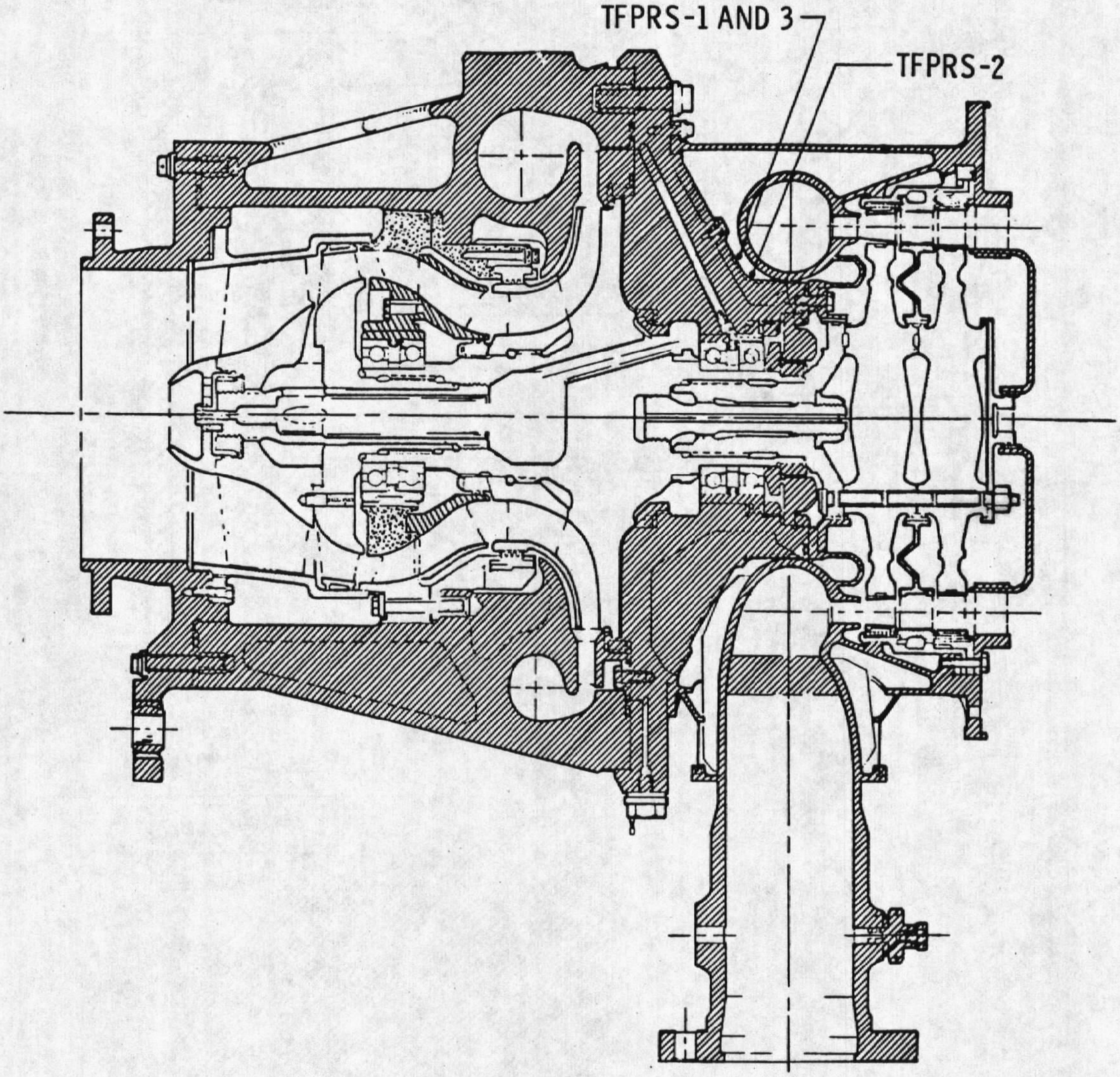
j. Helium Tank Sensor Locations
Fig. III-1 Continued



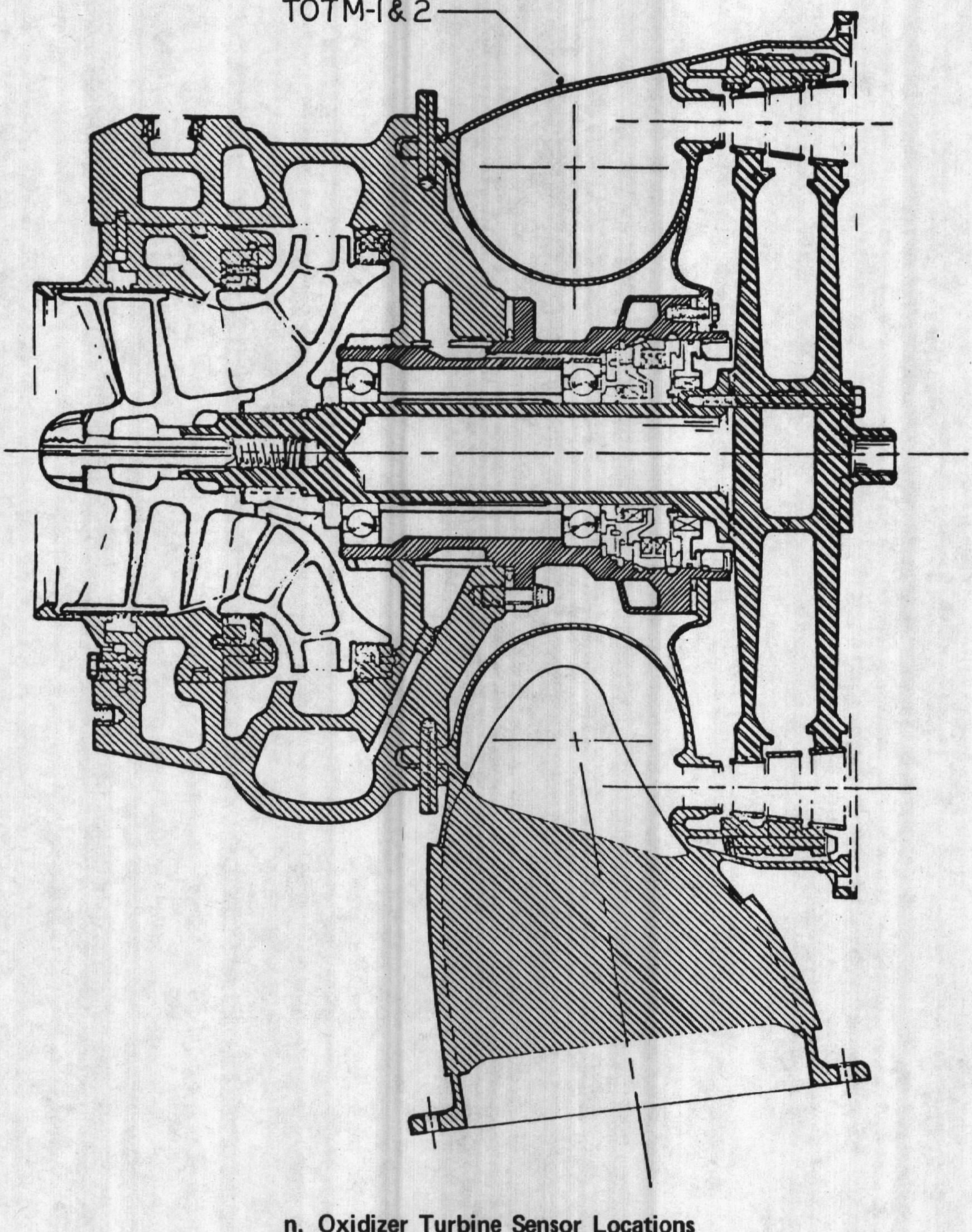
k. Solid-Propellant Turbine Starter Sensor Locations
Fig. III-1 Continued



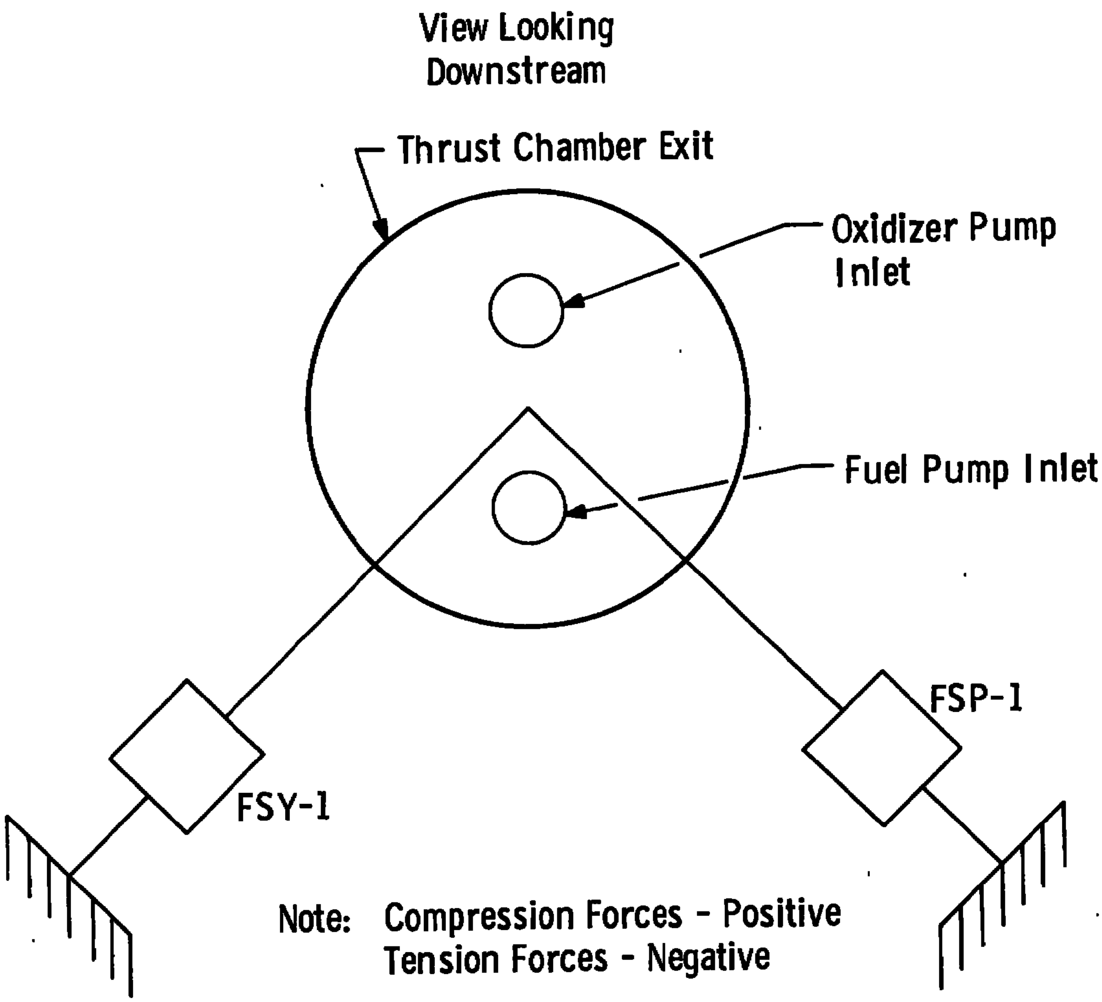
I. Solid-Propellant Turbine Starter Conditioning System Sensor Locations
Fig. III-1 Continued



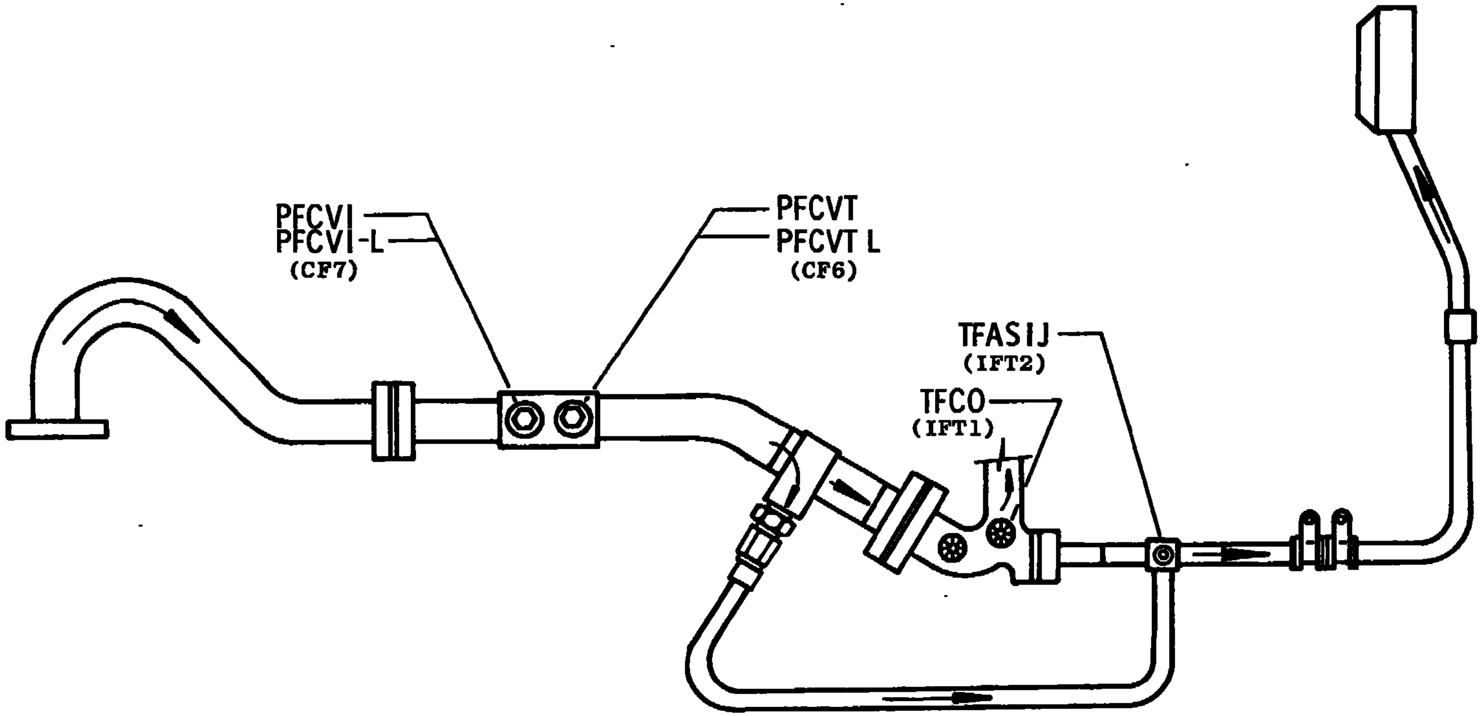
m. Fuel Turbine Sensor Locations
Fig. III-1 Continued



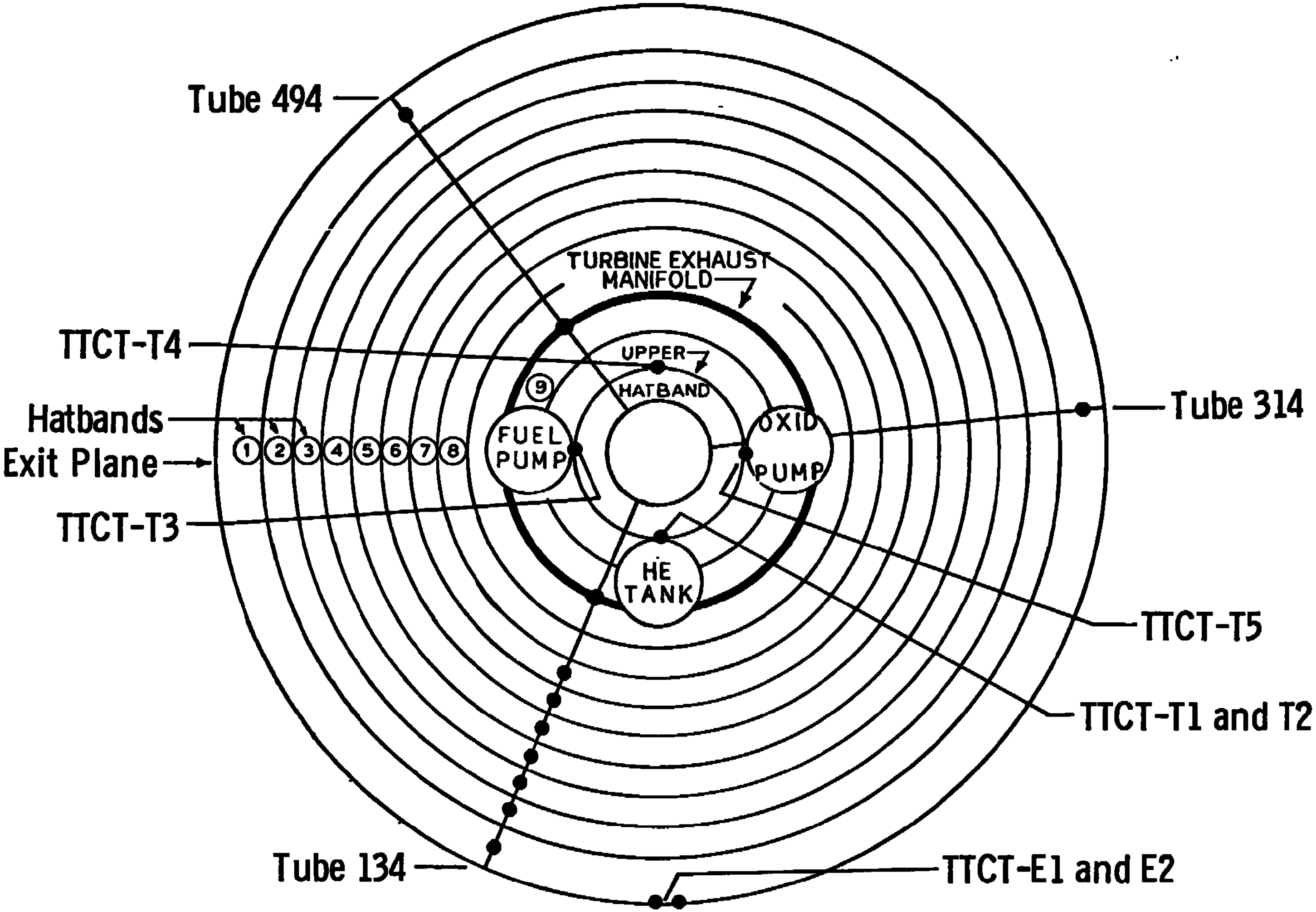
n. Oxidizer Turbine Sensor Locations
Fig. III-1 Continued



o. Side Load Forces Sensor Locations
Fig. III-1 Continued

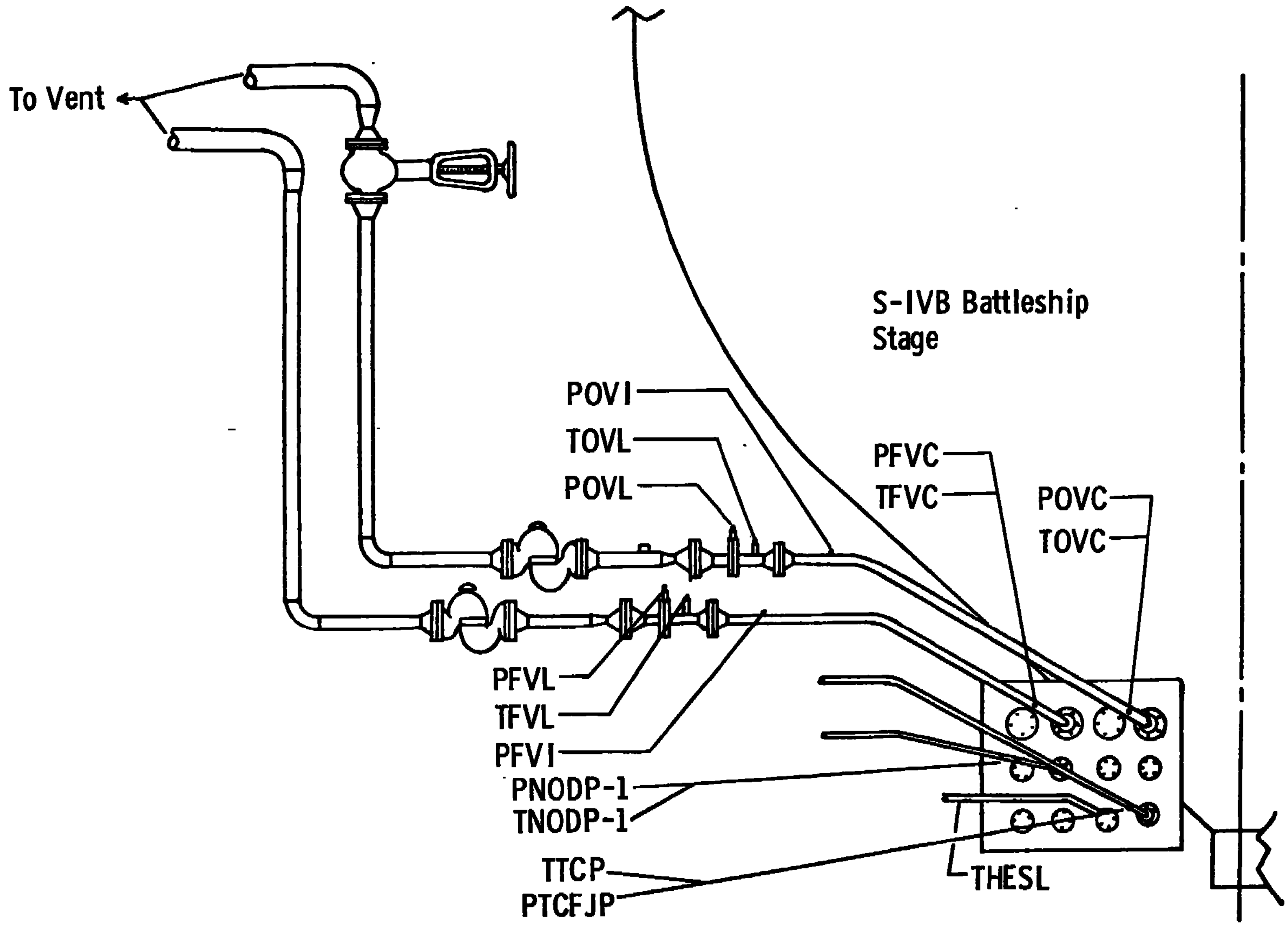


p. Augmented Spark Igniter/Film Coolant Fuel Line Assembly Instrumentation
Fig. III-1 Continued

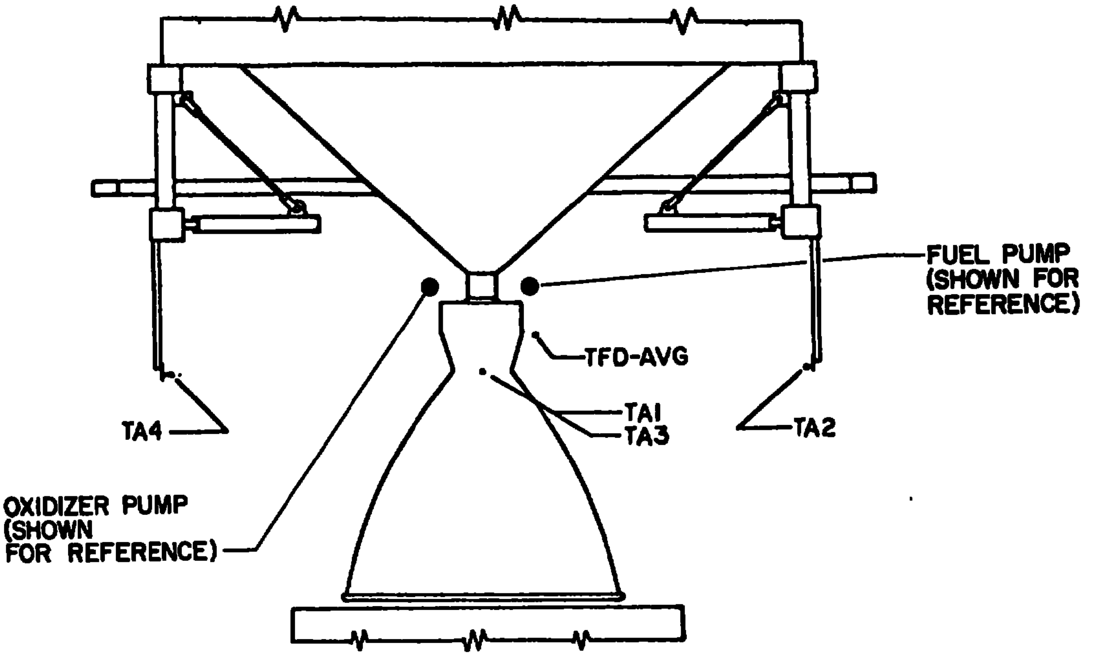


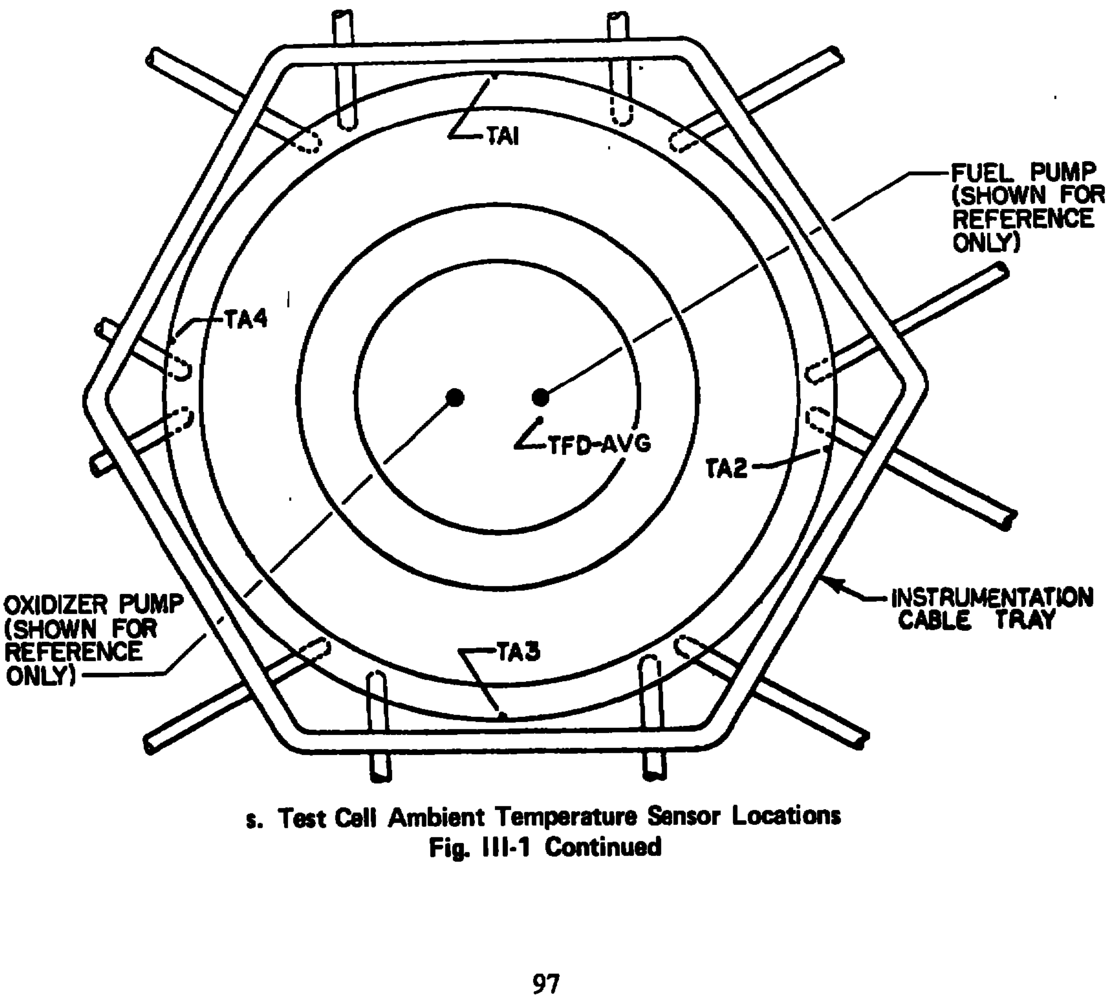
View Looking Aft

q. Thrust Chamber Sensor Locations
Fig. III-1 Continued

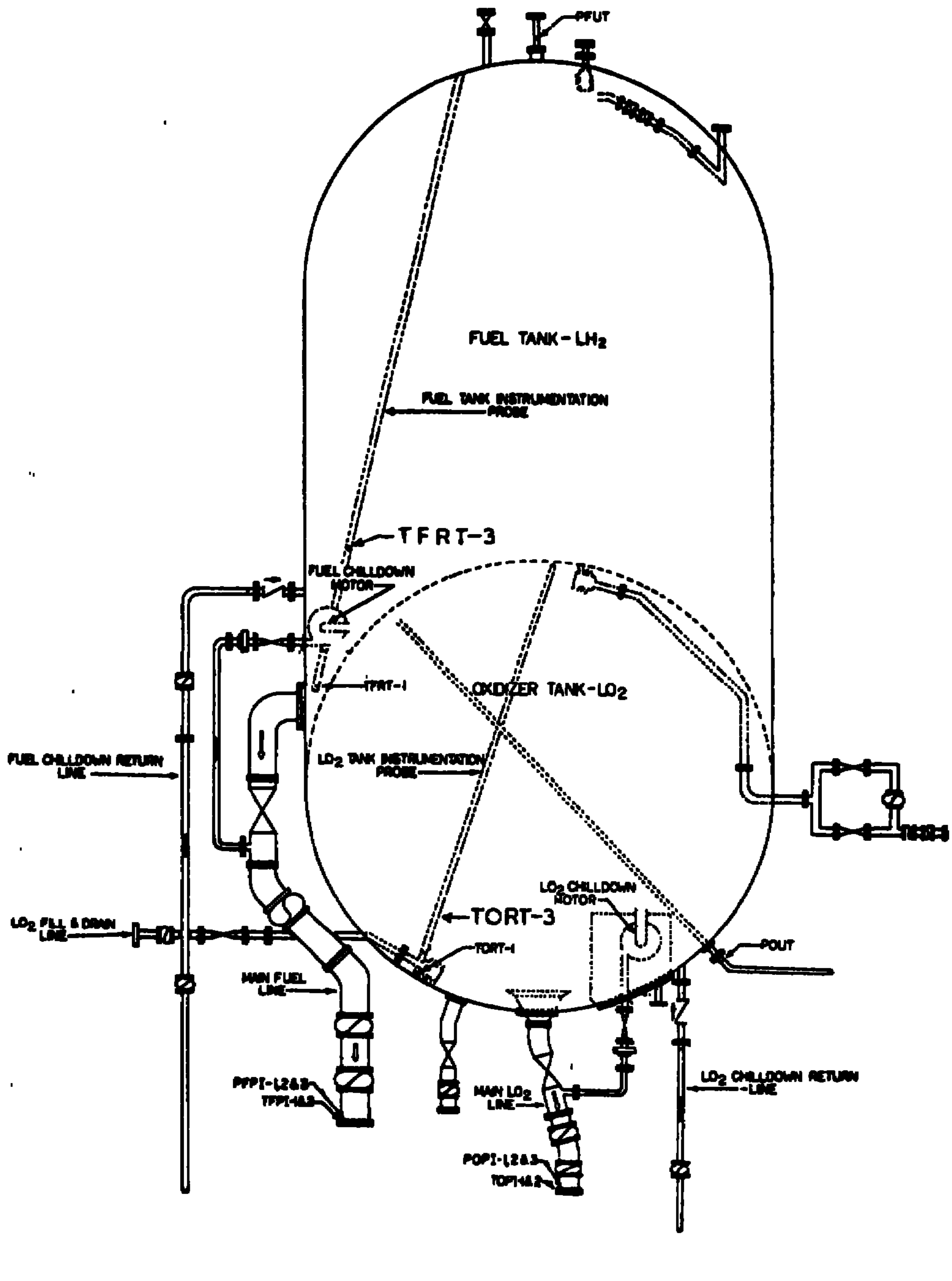


r. Customer Connect Panel Sensor Locations
Fig. III-1 Continued





s. Test Cell Ambient Temperature Sensor Locations
Fig. III-1 Continued



t. S-IVB Battleship Sensor Locations
Fig. III-1 Concluded

TABLE III-1
INSTRUMENTATION LIST

AEDC Code	Parameter	Tap No.	Range	Digital Data System	Magnetic Tape	Oscillo-graph	Strip Chart	Event Recorder	X-Y Plotter
	Current, amp								
ICC	Control		0 to 30	x					
IIC	Ignition		0 to 30	x					
	Event								
EASIS-1	Augmented Spark Igniter 1 Spark		On/Off					x	
EASIS-2	Augmented Spark Igniter 2 Spark		On/Off					x	
EECL	Engine Cutoff Lockin		On/Off	x		x		x	
EECO	Engine Cutoff Signal		On/Off	x		x		x	
EER	Engine Ready Signal		On/Off					x	
EES	Engine Start Command		On/Off	x		x		x	
EESCO	Programmed Duration Cutoff		On/Off					x	
EFBVO	Fuel Bleed Valve Open Limit		On/Off					x	
EFPCO	Fuel Pump Overspeed Cutoff		On/Off					x	
EFPVC	Fuel Prevalve Closed Limit		On/Off	x				x	
EFPVO	Fuel Prevalve Open Limit		On/Off	x				x	
EFUA	Exploding Bridge Wire Firing Units Armed		On/Off					x	
EHCS	Helium Control Solenoid Energized		On/Off	x	x	x		x	
EHGTC	Hot Gas Tapoff Valve Closed Limit		On/Off					x	
EHGTO	Hot Gas Tapoff Valve Open Limit		On/Off					x	
EID	Ignition Detected		On/Off	x		x		x	
EIDA-1	Ignition Detect Amplifier 1		On/Off					x	
EIDA-2	Ignition Detect Amplifier 2		On/Off					x	
EIMCS	Idle-Mode Control Solenoid Energized		On/Off	x		x		x	
EIMVC	Idle-Mode Valve Closed Limit		On/Off					x	
EIMVO	Idle-Mode Valve Open Limit		On/Off					x	
EMCL	Main-Stage Cutoff Lockin		On/Off	x		x		x	
EMCO	Main-Stage Cutoff Signal		On/Off	x		x			
EMCS	Main-Stage Control Solenoid Energized		On/Off	x		x		x	
EMD-1	Main Stage 1 "OK" Depressurized		On/Off	x		x		x	
EMD-2	Main Stage 2 "OK" Depressurized		On/Off	x		x		x	
EMFVC	Main Fuel Valve Closed Limit		On/Off					x	
EMFVO	Main Fuel Valve Open Limit		On/Off					x	
EMOVC	Main Oxidizer Valve Closed Limit		On/Off					x	

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Digital Data System	Magnetic Tape	Oscillograph	Strip Chart	Event Recorder	X-Y Plotter
	Event								
EMOVO	Main Oxidizer Valve Open Limit		On/Off					x	
EMP-1	Main Stage 1 "OK" Pressurized		On/Off	x		x		x	
EMP-2	Main Stage 2 "OK" Pressurized		On/Off	x				x	
EMPCO	Main-Stage Pressure Cutoff Signal		On/Off					x	
EMS	Main-Stage Start Signal		On/Off					x	
EMSCO	Main-Stage Programmed Duration Cutoff		On/Off					x	
EMSS	Main-Stage Start Solenoid Energized		On/Off	x	x	x		x	
EOBVO	Oxidizer Bleed Valve Open Limit		On/Off					x	
EOCO	Observer Cutoff Signal		On/Off					x	
EOPCO	Oxidizer Pump Overspeed Cutoff Signal		On/Off					x	
EOPVC	Oxidizer Prevalve Closed Limit		On/Off	x				x	
EOPVO	Oxidizer Prevalve Open Limit		On/Off	x				x	
EOTCO	Fuel Turbine Over-temperature Cutoff		On/Off					x	
ERASIS-1	Augmented Spark Igniter No. 1 Spark Rate		On/Off			x			
ERASIS-2	Augmented Spark Igniter No. 2 Spark Rate		On/Off			x			
ES1M1	No. 1 Solid-Propellant Turbine Starter Exploding Bridgewire No. 1 Monitor		On/Off	x		x			
ES1M2	No. 1 Solid-Propellant Turbine Starter Exploding Bridgewire No. 2 Monitor		On/Off	x		x			
ES2M1	No. 2 Solid-Propellant Turbine Starter Exploding Bridgewire No. 1 Monitor		On/Off	x		x			
ES2M2	No. 2 Solid-Propellant Turbine Starter Exploding Bridgewire No. 2 Monitor		On/Off	x		x			
ES3M1	No. 3 Solid-Propellant Turbine Starter Exploding Bridgewire No. 1 Monitor		On/Off	x		x			
ES3M2	No. 3 Solid-Propellant Turbine Starter Exploding Bridgewire No. 2 Monitor		On/Off	x		x			
ESAMCO	Stall Approach Monitor Cutoff		On/Off					x	
ESPTS	Solid-Propellant Turbine Starter Initiated		On/Off					x	

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Digital Data System	Magnetic Tape	Oscillograph	Strip Chart	Event Recorder	X-Y Plotter
	Event								
ESR-1	No. 1 Solid-Propellant Turbine Starter Ready		On/Off	x		x		x	
ESR-2	No. 2 Solid-Propellant Turbine Starter Ready		On/Off	x		x		x	
ESR-3	No. 3 Solid-Propellant Turbine Starter Ready		On/Off	x		x		x	
ESTCO	Start "OK" Timer Cutoff Signal		On/Off					x	
ETCBC	Thrust Chamber Bypass Valve Closed		On/Off					x	
ETCBO	Thrust Chamber Bypass Valve Open		On/Off					x	
EVSC-1	Vibration Safety Counts No. 1		On/Off			x			
EVSC-2	Vibration Safety Counts No. 2		On/Off			x			
EVSC-3	Vibration Safety Counts No. 3		On/Off			x			
	Flows, gpm								
QF-1	Engine Fuel	PFF	0 to 11,000	x					
QF-2	Engine Fuel	PFFa	0 to 11,000	x	x	x			
QF-3	Engine Fuel	PFF	0 to 11,000			x			
QO-1	Engine Oxidizer	POF	0 to 3,600	x					
QO-2	Engine Oxidizer	POFa	0 to 3,600	x	x	x			
QO-3	Engine Oxidizer	POF	0 to 3,600			x			
	Forces, lbf								
FSP-1	Side Load (Pitch)		±20,000	x		x			
FSY-1	Side Load (Yaw)		±20,000	x		x			
	Position, percent open								
LFBT	Thrust Chamber Bypass Valve		0 to 100	x		x			
LFVT	Main Fuel Valve		0 to 100	x		x			
LIMT	Idle-Mode/Augmented Spark Igniter Oxidizer Valve		0 to 100	x		x			
LOVT	Main Oxidizer Valve		0 to 100	x		x			
LPUTOP	Propellant Utilization Valve		5 volts	x		x	x		
LTVT	Hot Gas Tapoff Valve		0 to 100	x		x			
	Pressure, psia								
PA-1	Test Cell		0 to 0.5	x					
PA-2	Test Cell		0 to 1.0	x					
PA-3	Test Cell		0 to 5.0	x		x	x		

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Digital Data System	Magnetic Tape	Oscillo-graph	Strip Chart	Event Recorder	X-Y Plotter
	Pressure, psia								
PC-1P	Thrust Chamber	CG1	0 to 1500	x					
PC-2P	Thrust Chamber	CG1a-2	0 to 1500	x		x	x		
PC-2PL	Thrust Chamber	CG1a-1	0 to 50	x		x			
PCSPTS-1	Solid-Propellant Turbine Starter No. 1 Chamber	PTS-1	0 to 5000	x		x			
PCSPTS-2	Solid-Propellant Turbine Starter No. 2 Chamber	PTS-2	0 to 5000	x		x			
PCSPTS-3	Solid-Propellant Turbine Starter No. 3 Chamber	PTS-3	0 to 5000	x		x			
PFBM	Thrust Chamber Bypass Manifold	CF3	0 to 1500	x					
PFCO	Film Coolant Orifice	CF5	0 to 2000	x					
PFCO-L	Film Coolant Orifice	CF5	0 to 50	x					
PFCVI	Film Coolant Venturi Inlet	CF7	0 to 2000	x					
PFCVI-L	Film Coolant Venturi Inlet	CF7	0 to 50	x					
PFCVT	Film Coolant Venturi Throat	CF6	0 to 2000	x					
PFCVT-L	Film Coolant Venturi Throat	CF6	0 to 50	x					
PFJ-1	Fuel Injection	CF2	0 to 1500	x					
PFJ-1L	Fuel Injection	CF2	0 to 50	x					
PFMI	Fuel Jacket Manifold Inlet	CF1	0 to 2000	x					
PFMI-L	Fuel Jacket Manifold Inlet	CF1	0 to 50	x					
PFPBC	Fuel Pump Balance Piston Cavity	PF5	0 to 2000	x		x		x	
PFPBS	Fuel Pump Balance Piston Sump	PF4	0 to 1000	x		x		x	
PFPD-1L	Fuel Pump Discharge	PF3	0 to 50	x					
PFPD-1P	Fuel Pump Discharge	PF3	0 to 2500	x				x	
PFPI-1	Fuel Pump Inlet	PF1	0 to 2500	x					x
PFPI-2	Fuel Pump Inlet		0 to 100	x					x
PFPI-3	Fuel Pump Inlet	PF1a	0 to 100	x	x	x			
PFPRB	Fuel Pump Rear Bearing Coolant	PF7	0 to 1000	x					
PFPS	Fuel Pump Interstage	PF6	0 to 1000	x		x	x		
PFPSI	Fuel Pump Shroud Inlet		0 to 2500	x			x		

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Digital Data System	Magnetic Tape	Oscillo-graph	Strip Chart	Event Recorder	X-Y Plotter
	Pressure, psia								
PFTI-1P	Fuel Turbine Inlet	TG1	0 to 1000	x		x			
PFTO	Fuel Turbine Outlet	TG2	0 to 200	x					
PFTSC	Fuel Turbine Seal Cavity	TG10	0 to 500	x					
PFUT	Fuel Ullage Tank		0 to 100	x					
PFVC	Fuel Repressurization at Customer Connect Panel		0 to 2000	x					
PFVI	Fuel Repressurization Nozzle Inlet	KHP1	0 to 2000	x					
PFVL	Fuel Repressurization Nozzle Throat	KHP2	0 to 1000	x					
PHEA	Helium Accumulator	NN3	0 to 750	x					
PHES	Helium Supply		0 to 5000	x					
PHET-1P	Helium Tank	NN1 -1	0 to 5000	x					x
PHET-2P	Helium Tank	NN1 -3	0 to 5000	x					
PHRO-1P	Helium Regulator Outlet	NN2	0 to 750	x					
PNODP-1	Oxidizer Dome Purge at Customer Connect Panel		0 to 750	x					
PNODP-2	Oxidizer Dome Purge at Custom Connect Panel		0 to 1500	x					
POASIJ	Augmented Spark Igniter Oxidizer Injection	IO3	0 to 1500	x		x			
POASIJ-L	Augmented Spark Igniter Oxidizer Injection	IO3	0 to 50	x					
POIML-3	Oxidizer Idle-Mode Line	PO10	0 to 2000		x				
POJ-1	Oxidizer Injection	CO3	0 to 1500	x					
POJ-2	Oxidizer Injection	CO3a	0 to 1500	x		x			
POJ-3	Oxidizer Injection Manifold	CO3b	0 to 500		x	x			
POPBC	Oxidizer Pump Bearing Coolant	PO7	0 to 500	x					
POPD-1L	Oxidizer Pump Discharge	PO3	0 to 50	x					
POPD-1P	Oxidizer Pump Discharge	PO3	0 to 2500	x					
POPD-2	Oxidizer Pump Discharge	PO2	0 to 3000	x	x	x			
POPI-1	Oxidizer Pump Inlet	PO1	0 to 100	x					x
POPI-2	Oxidizer Pump Inlet		0 to 100	x					x
POPI-3	Oxidizer Pump Inlet	PO1a	0 to 100	x	x	x			
POPSC	Oxidizer Pump Primary Seal Cavity	PO6	0 to 50	x					
POTI-1P	Oxidizer Turbine Inlet	TG3	0 to 200	x					

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Digital Data System	Magnetic Tape	Oscillo-graph	Strip Chart	Event Recorder	X-Y Plotter
	Pressure, psia								
POTO-1P	Oxidizer Turbine Outlet	TG4	0 to 100	x					
POUT	Oxidizer Ullage Tank		0 to 100	x					
PPTD	Photocon Cooling Water (Downstream)		0 to 100	x					
PPTU	Photocon Cooling Water (Upstream)		0 to 100	x					
PPUVI	Propellant Utilization Valve Inlet	PO8	0 to 2000	x					
PPUVO	Propellant Utilization Valve Outlet	PO9	0 to 1000	x					
PTCFJP	Thrust Chamber Fuel Jacket Purge		0 to 200	x					
PTEM	Turbine Exhaust Manifold	TG5	0 to 50	x					
PTM	Tapoff Manifold	GG2b	0 to 1500	x					
PTM-L	Tapoff Manifold	GG2b	0 to 50	x		x			
	Speeds, rpm								
NFP-1	Fuel Pump	PPV	0 to 33,000		x				
NFP-2	Fuel Pump	PPV	0 to 33,000	x					
NFP-3	Fuel Pump	PPV	0 to 33,000			x			
NOP-1	Oxidizer Pump	POV	0 to 12,000		x				
NOP-2	Oxidizer Pump	POV	0 to 12,000	x					
NOP-3	Oxidizer Pump	POV	0 to 12,000			x			
	Temperatures, °F								
TA-1	Test Cell North		-50 to 800	x					
TA-2	Test Cell East		-50 to 800	x					
TA-3	Test Cell South		-50 to 800	x					
TA-4	Test Cell West		-50 to 800	x					
TECP-1P	Electrical Control Assembly	NST1a	-300 to 200	x					
TFBM	Fuel Bypass Manifold		-425 to 100	x					
TFCO	Film Coolant Orifice	IFT1	-425 to 375	x					
TFD-Avg.	Fire Detection Average		0 to 1000	x			x		
TFDFTA	Fire Detect Fuel Turbine Manifold Area		0 to 500	x					
TFDMFVA	Fire Detect Main Fuel Valve Area		0 to 500	x					
TFDMOVA	Fire Detect Main Oxidizer Valve Area		0 to 500	x					
TFDODA	Fire Detect Oxidizer Dome Area		0 to 500	x					
TFDTDA	Fire Detect Tapoff Duct Area		0 to 500	x					
TFJ-1P	Fuel Injection	CFT2	-425 to -300	x					

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Digital Data System	Magnetic Tape	Oscillo-graph	Strip Chart	Event Recorder	X-Y Plotter
	Temperatures, °F								
TFJ-2P	Fuel Injection	CFT2a	-425 to 100	x		x	x		
TFPBS	Fuel Pump Balance Piston Sump	PFT4	-425 to -375	x					
TFPD-1P	Fuel Pump Discharge	PFT1	-425 to -300	x	x				
TFPD-2P	Fuel Pump Discharge	PFT1	-425 to 100	x					
TFPD-3	Fuel Pump Discharge	PF3	-425 to -300	x					
TFPD-4	Fuel Pump Discharge	PF3	-425 to 100	x					
TFPI-1	Fuel Pump Inlet	KFT2	-425 to -400	x					x
TFPI-2	Fuel Pump Inlet	KFT2a	-425 to 100	x					x
TFPRS-1	Fuel Pump Rear Support		-400 to 1800	x					
TFPRS-2	Fuel Pump Rear Support		-400 to 1800	x					
TFPRS-3	Fuel Pump Rear Support		-400 to 1800	x					
TFRT-1	Fuel Run Tank		-425 to -400	x					
TFRT-3	Fuel Run Tank		-425 to -400	x					
TFTI-3	Fuel Turbine Inlet	TGT1	-300 to 2400	x			x		
TFTO	Fuel Turbine Outlet		-100 to 1200	x					
TFVC	Fuel Repressurization at Customer Connect Panel		-300 to -100	x					
TFVL	Fuel Repress. Nozzle Inlet	KHPT1	-300 to -100	x					
THFT-1P	Helium Tank	NNT1	-200 to 300	x					x
TMFVS-1	Main Fuel Valve Skin (Outer Wall)		-425 to 100	x			x		
TMFVS-2	Main Fuel Valve Skin (Inner Wall)		-425 to 100	x					
TMOVF	Main Oxidizer Valve Upstream Flange		-300 to 100	x					
TNODP-1	Oxidizer Dome Purge		-250 to 200	x					
TNODP-2	Oxidizer Dome Purge		-250 to 200	x					
TOIML	Oxidizer Idle-Mode Line	POT5	-300 to 100	x					
TOJ	Oxidizer Injection	COT1	-300 to 1200	x		x			
TOPBC	Oxidizer Pump Bearing Coolant	POT4	-300 to 100	x			x		
TOPDF	Oxidizer Pump Discharge Flange		-300 to 100	x					
TOPD-1P	Oxidizer Pump Discharge	POT3	-300 to -250	x					
TOPD-2P	Oxidizer Pump Discharge	POT3	-300 to 100	x					

TABLE III-1 (Continued)

AEDC Code	Parameter	Tap No.	Range	Digital Data System	Magnetic Tape	Oscillo-graph	Strip Chart	Event Recorder	X-Y Plotter
	Temperatures, °F								
TOPVS	Oxidizer Pump Volute Skin		-300 to 100	x					
TOPI-1	Oxidizer Pump Inlet	KOT2	-310 to -250	x					x
TOPI-2	Oxidizer Pump Inlet	KOT2a	-310 to 100	x					x
TORT-1	Oxidizer Run Tank		-300 to -285	x					
TORT-3	Oxidizer Run Tank		-300 to -285	x					
TOTI-1P	Oxidizer Turbine Inlet	TGT3	0 to 1200	x					
TOTM-1	Oxidizer Turbine Manifold		-300 to 1000	x					
TOTM-2	Oxidizer Turbine Manifold		-300 to 1000	x					
TOTO-1P	Oxidizer Turbine Outlet	TGT4	0 to 1000	x					
TPIP-1P	Instrumentation Package		-300 to 200	x					
TPTU	Photocon Cooling Water (Upstream)		0 to 300	x					
TSCGA-1	Solid-Propellant Turbine Starter No. 1 Cond. Gas		-100 to 300	x					
TSCGA-2	Solid-Propellant Turbine Starter No. 2 Cond. Gas		-100 to 300	x					
TSCGA-3	Solid-Propellant Turbine Starter No. 3 Cond. Gas		-100 to 300	x					
TSCMF-1	Solid-Propellant Turbine Starter Case Mount Flange		0 to 1500	x					
TSCMF-2	Solid-Propellant Turbine Starter Case Mount Flange		0 to 1500	x					
TSCMF-3	Solid-Propellant Turbine Starter Case Mount Flange		0 to 1500	x					
TTCP	Thrust Chamber Purge		-250 to 200	x					
TTCT-E1	Thrust Chamber Tube (Exit)		-425 to 500	x					
TTCT-E2	Thrust Chamber Tube (Exit)		-425 to 500	x					
TTCT-T1	Thrust Chamber Tube (Throat)		-425 to 500	x			x		
TTCT-T2	Thrust Chamber Tube (Throat)		-425 to 500	x					
TTCT-T3	Thrust Chamber Tube (Throat)		-425 to 500	x					
TTCT-T4	Thrust Chamber Tube (Throat)		-425 to 500	x					

TABLE III-1 (Concluded)

AEDC Code	Parameter	Tap No.	Range	Digital Data System	Magnetic Tape	Oscillo- graph	Strip Chart	Event Recorder	X-Y Plotter
	Temperatures, °F								
TTCT-T5	Thrust Chamber Tube (Throat)		-425 to 500	x					
TTM	Tapoff Manifold		0 to 2000	x		x	x		
	Peak Vibrations, g								
UOPR	Oxidizer Pump	PZA-2	300		x				
UTCD-1	Thrust Chamber Dome	PZA-1a	212		x	x			
UTCD-2	Thrust Chamber Dome	PZA-2	212		x	x			
UTCD-3	Thrust Chamber Dome	PZA-3	212		x	x			
UTCD-4	Thrust Chamber Dome		1400		x				
UTCT-1	Thrust Chamber Throat		300		x				
UTCT-2	Thrust Chamber Throat		300		x				
	Voltage, v								
VCB	Control Bus		0 to 36	x					
VIB	Ignition Bus		0 to 36	x					
VIDA-1	Ignition Detect Amplifier		9 to 16	x					
VIDA-2	Ignition Detect Amplifier		9 to 16	x					
VPUVEP	Propellant Utilization Valve Telemetry Potentiometer Excitation		0 to 5	x					

APPENDIX IV
POWER SPECTRAL DENSITY WAVE ANALYSIS

The characteristics of a time-history signal can be described as being random, periodic, or a combination of random and periodic. These characteristics can best be understood if represented by some measure of the spectral characteristics for the signal. The spectral characteristics for any signal may be displayed as an amplitude versus frequency plot, called a frequency spectrum. The frequency spectrum for a periodic signal consists of discrete amplitude components at specific frequencies having a common multiple. The frequency spectrum for a random signal is continuous with response amplitudes possible in any frequency interval but with no discrete components at any specific frequency. Therefore, the frequency spectrum for a random signal must be presented in terms of a continuous spectral density versus frequency plot.

The most meaningful spectral density function is a density function measured in terms of mean-square values per unit frequency. Such a function is called a power spectral density function. The frequency spectrum produced by plotting a power spectral density function versus frequency is called a power spectrum.

The power spectral density is mathematically defined as

$$Gy\,(f) = \lim_{T\to\infty} \lim_{\Delta f\to 0} \frac{1}{(\Delta f)\,T}\left[\int_0^T y^2_{\Delta f}\,(f,t)\,dt\right] \tag{IV-1}$$

where $y^2_{\Delta f}(f,t)$ is the squared instantaneous amplitude of the signal within the narrow frequency interval from f Hz to f + Δf Hz.

The electronic equipment processes necessary to produce the exact mathematical operations required for the power spectral density equation are not possible since infinitely long averaging times (T) and infinitesimally narrow frequency intervals (Δf) are physically impossible to obtain. A power spectral density function for a stationary random signal y(t) may be approximated as

$$\hat{G}y\,(f) = \frac{1}{BT}\int_0^T y^2_B\,(f,t)\,dt = \frac{\overline{y^2_B\,(f)}}{B} \tag{IV-2}$$

where $\overline{y^2_B(f)}$ is the mean-square value of the signal within a narrow frequency of f Hz, and T is a finite averaging time in seconds. Equation (IV-2) is mechanized by the wave analyzer as shown in Fig. IV-1.

The approximations made in Eq. (IV-2), although inherent in a practical measurement system introduce a measurement uncertainty or statistical variance. This uncertainty can be predicted to a 67-percent confidence level by the formula

$$\epsilon = \frac{1}{\sqrt{BT}}$$

where	ϵ	is the standard error,
	B	is the effective filter bandwidth,
	T	is the integration time = 4K
and	K	is the time constant of the averaging circuit.

For the data analyzed with a 10-Hz bandwidth and a time constant of 1 sec, the standard error is

$$\epsilon = \frac{1}{\sqrt{(10)\,(4)\,(1)}} = 0.158 = 15.8 \text{ percent}$$

This would produce a power spectral density plot with 67 percent of the points falling within 15.8 percent of the true value.

At this point, it is obvious that a tradeoff must be made when determining data reduction requirements. A large averaging time, T, would tend to allow a smaller error. However, the larger T is made, the longer is the time necessary to produce a single plot. Again, the larger B is made, the smaller ϵ becomes. This, however, leads to problems in frequency resolutions. Also, since in the power spectral density plot one must divide by bandwidth, a large bandwidth reduces the signal peaks while increasing the width of the pulse. If care is not taken, the data could be overlooked entirely.

Power spectral density analyses presented in this report were made with various bandwidth filters. The values of these filters and the associated standard error are summarized below:

Bandwidth, Hz	Standard Error, percent	Frequency Range, Hz
10	15.8	10 to 500
50	7.1	500 to 10,000

I. MAIN-STAGE PERFORMANCE

A. Propellant Flow Rates

Oxidizer

$\dot{w}_o$ = K_1 K_2 ρ (flowmeter output, Hz), lbm/sec
K_1 = 1/5.5, gal/cycle
K_2 = 1/7.48, cu ft/gal
ρ = ρ (TOPD, POPD), lbm/cu ft

Fuel

$\dot{w}_f$ = K K_2 ρ (flowmeter output, Hz), lbm/sec
K = 1/2.0, gal/cycle
K_2 = 1/7.48, cu ft/gal
ρ = ρ (TFPD, PFPD), lbm/cu ft

Total

$\dot{w}_t = \dot{w}_o + \dot{w}_f$

B. Mixture Ratio

$MR = \dot{w}_o/\dot{w}_f$

C. Vacuum-Corrected Thrust

F_{ev} = [193.73 + 3.34 (MR)] $P_c + P_a A_e$, lbf

where

A_e = 4643.3 sq in.

D. Vacuum-Corrected Specific Impulse

$I_{spv} = F_{ev}/\dot{w}_t$, lbf-sec/lbm

E. Characteristic Velocity

$C^* = P_c A^* g/\dot{w}_t$, ft/sec

where

A^* = 117.1 sq in.

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ALTITUDE DEVELOPMENTAL TESTING OF THE J-2S ROCKET ENGINE IN ROCKET DEVELOPMENT TEST CELL (J-4) (TESTS J-4-1001-04 AND J-4-100k-05)

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C. R. Tinsley and C. E. Pillow, ARO, Inc.

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13. ABSTRACT

Five firings of the Rocketdyne J-2S rocket engine were conducted in Rocket Development Test Cell (J-4) of the Engine Test Facility on July 17 and 29, 1969. These firings were accomplished during test periods J4-1001-04 and J4-1001-05 at pressure altitudes ranging from 85,000 to 101,000 ft at engine start. The primary objectives of these test periods were to (1) determine if main-stage conditions which existed during sea-level testing of engine S/N J-113 would result in similar abnormal oxidizer dome vibrations in the 4400- to 4700-Hz frequency range during altitude testing of engine J-112-E, (2) evaluate high thrust idle-mode operation with a simulated full-face oxidizer flow injector configuration, and (3) document effects of closing the thrust chamber bypass valve during high thrust idle-mode operation. Altitude testing did not result in abnormal (greater than 100 g rms) oxidizer dome vibration in the 4400- to 4700-Hz range during test period 04. The thrust chamber bypass valve closing resulted in a 65°F increase in fuel injection temperature; however, stabilized high thrust idle-mode operation was not attained during test period 05.

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